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A STUDY OF THE CANOPY DESIGN FOR THE ADVANCED ATTACK HELICOPTER--ETC(U)
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Technical Memorandum 13-79

A STUDY OF THE CANOPY DESIGN FOR THE ADVANCED ATTACK HELICOPTER BY USE OF COMPUTER GRAPHICS

Christopher C. Smyth

August 1979
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U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A package of computer programs has been developed by the US Army Human Engineering Laboratory for use in helicopter canopy design. The programs compute point-wise measures of three important design factors for the transparent surfaces of an attack helicopter canopy. These factors are (1) the internal glare, (2) the external glint, and (3) the optical distortions exhibited by the canopy design. The programs have been applied to modifications in the present canopy design on the Model YAH-64 Advanced

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20. ABSTRACT (Continued)

Attack Helicopter. The results suggest that reduced internal glare is possible with slight additional glint and distortion by displacing the side windows 4 inches from the ~~vertice plane~~ and rotating the axis of curvature of the top window by 90 degrees and displacing it 1.5 inches.

plane of the frame vertices

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A STUDY OF THE CANOPY DESIGN FOR THE ADVANCED ATTACK HELICOPTER BY USE OF COMPUTER GRAPHICS

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Aberdeen Proving Ground, Maryland 21005

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A STUDY OF THE CANOPY DESIGN FOR THE ADVANCED ATTACK

HELICOPTER BY USE OF COMPUTER GRAPHICS

INTRODUCTION

The US Army Human Engineering Laboratory (USAHEL) has developed a package of computer programs for attack helicopter canopy design. The programs compute point-wise measures of three important design factors for the transparent surfaces of an attack helicopter canopy design. These factors are (1) the internal glare, (2) the external glint, and (3) the optical distortions exhibited by the canopy design. This work was undertaken at the request of the Project Manager's Office, USA Aircraft Survivability Equipment (ASE), and is part of an effort by HEL to determine optimum canopy designs for the Model 209 AH-1S Cobra Helicopter and the Model YAH-64 Advanced Attack Helicopter (AAH).

A current problem in military helicopter design is the choice of an optimum configuration for the transparent surfaces of the helicopter canopy. The design should satisfy several conflicting requirements. First, the canopy should reflect a minimum of solar glint to external observers during daytime operations. The design should exhibit a minimum of internal reflections of the internal instrument lights and external light sources during nighttime operations. Finally, the canopy design should not distort the pilot's visibility of distant scenes during flight. The need for these requirements has become apparent during the recent history of attack helicopter development.

The Model 209 AH-1G COBRA, a predecessor to the AAH, was equipped with a compound-curved canopy. The aircraft reflected a continual solar glint when operated in daylight under clear skies. The glint was highly visible and enabled distant ground observers to readily detect and track the helicopter, thereby placing it at a tactical disadvantage.

A flat plate canopy (FPC) design was developed for the later model COBRA, the AH-1S, and the AAH. The design reduced the solar glint to momentary flashes which occurred at a limited number of observer-aircraft-sun angles. A moving aircraft no longer produced the continual solar glint which was present on the earlier compound-curved canopy designs.

However, the internal surfaces of the FPC acted as mirrors reflecting virtual images of external light sources during nighttime operations. HEL has shown by computer analysis (4,6), that these reflections can occur on most of the canopy surfaces and for a wide range of external source locations. In certain lighting situations, these virtual images of ground level lights so disorientated the pilot that he could not easily discriminate between the light sources on the ground and their reflections from the canopy surfaces. The use of the FPC as a solution to daytime glint problems resulted in a potential safety hazard during nighttime flight.

A low glare canopy (LGC) design was developed for the Model YAH-64 AAH. The design has little solar glint and lower internal glare than the FPC design. The LGC consists of flat transparent panels on the front, the same as on the FPC, but the top and sides are slightly bowed in the shape of simple cylindrical segments. HEL recommended a similar design with several novel features (6). The question of interest is how effective is the low glare design in controlling glint and internal glare, and is it possible to develop an optimal design.

The computer programs developed by HEL have been applied to perturbations in the present LGC design for the Model YAH-64 AAH. The programs computed the internal glare, external glint and optical distortions as a function of the displacements of the top and side cylindrical panels from the vertice planes. This report presents the methods and results of the study.

METHOD

A set of computer programs was written to compute point-wise measures of three important design factors for the transparent surfaces of a helicopter canopy design. The factors are (1) the internal glare, (2) the external glint, and (3) the optical distortions. A description of each program and the computing method employed follows along with a discussion of the program's input data.

Internal Glare

The computer program (see Appendix C) determines all points, spaced at equal angular increments, where the pilot can see reflections on the canopy surface of external light sources. The program computes the coordinates and reflectances of the reflection points and the directions of the corresponding light sources. The program is an extension of ray tracing techniques developed earlier (4,5), and computes secondary and higher order reflections as well as primary orders. The results determine the portions of the canopy surface which are open to possible reflections. The reflection points are plotted on side, top, and front views of the canopy frame. The total number of reflection points are printed out for each window.

External Glint

The computer program (Appendix C) computes the angular direction of the specular reflections of solar glint from the transparent surfaces of the helicopter canopy. The angular directions of the solar glint are computed for any specified range of sun-aircraft angles.

The program first determines a grid of equally spaced surface points on the windows of the canopy. The program then computes the direction of the specular reflection at each surface point for each of the specified sun positions (see Appendix A). The directions are next plotted as points on a rectangular plot as a function of elevation and azimuth. The collection of such reflection points for a specified sun-position shows the range of directions from which the aircraft can be seen by distant observers. A collection of such reflection points are plotted for each of the specified sun-positions. The position of the sun and the reflection direction are measured as elevation and azimuth angles in the coordinate system of the aircraft (see Appendix A).

Optical Distortions

The computer program (Appendix C) computes the light transmittance and optical distortion for equally spaced surface points on the transparent surfaces of the canopy. The program first determines a grid of equally spaced surface points on the windows of the canopy. The program then computes the light transmittance and optical distortion for each surface point as seen from the pilot's nominal eye position (see Appendix B).

The program computes the light transmittance for the straight line ray from the surface point to the pilot's eye. The ray is traced backwards through the canopy surface to the outside. The transmittance is the product of the transmittances at the inside and outside surfaces, and that not absorbed by the window material.

The optical distortion is computed for each surface point as the *square-root* error of the lateral magnification. A family of rays is constructed for a 4-degree cone of vision centered about the principal ray from the surface point to the pilot's eye. The rays are chosen in such a manner that the solid angles contained by adjacent rays are equal. The lateral magnification is computed for each ray in the cone by tracing the ray backwards through the surface and then computing the angle between the incident and transmitted rays. The square-root error is computed as the square root of the sum of the squares of the differences between the magnification for the principal ray and each ray, divided by the number of rays in the cone. The computed measure is equal to zero for a surface which has no distortions.

The program plots the computed values of the transmittance and optical distortion on side, top, and front views of the canopy frame. The plots allow the user to determine which areas of the canopy distort the pilot's distant vision.

Program Input Data

The canopy frame positions and the shape of the transparent windows are specified as input to the programs. The transparent surfaces of the canopy design are specified as a set of planar and cylindrical surfaces and their corresponding edge vertices. Each planar surface is specified by the coordinates of its edge vertices and the consecutive order in which adjacent vertices are listed. A cylindrical surface is specified by cylindrical parameters and the consecutive sequence of the edge vertices and their coordinates. The cylindrical parameters are (1) the origin point on the cylindrical axis, (2) the directional cosines of the axis, and (3) the radius of the cylinder. The edges of the cylindrical surface are assumed for simplicity to be curvilinear lines which project into straight lines when the cylinder is transformed into a flat plane.

The programs are tailored to the YAH-64 AAH low glare canopy design, but are applicable to any helicopter given the canopy frame positions and the parameters of the transparent surfaces. The programs compute the measures of the design factors as functions of the displacement of the cylindrical windows. The displacement is measured along the cylindrical radius normal to the plane of the frame vertices, and is the distance between the plane and the cylindrical side.

RESULTS

The computed results for the three design factors are shown in the figures for pertinent combination of the side and top window displacements on the Model YAH-64 Advanced Attack Helicopter (AAH). The results are treated separately in the following sections.

Internal Glare

Figures 1 through 14 show where internal glare can occur on the canopy surfaces. The figures show the top, side, and front views of the canopy frame. The figures are paired for a given combination of the window displacement values. The first figure of a pair shows the possible reflection points on the surface. A numeral zero or one, corresponding to the associated reflectance value, is shown at the surface position. The second figure shows the entry positions of those rays which are reflected. All but the last set of figures correspond to a 2-degree by 2-degree viewing increment. The last set corresponds to a 0.5-degree by 0.5-degree increment. The figures show primary reflection points. The secondary and triplex reflection points, computed by the same method, are discussed in the DISCUSSION section.

Figures 1 through 10 show the internal glare for increasing values of the side window displacement. The displacement is measured along the cylindrical radius in a direction normal to the plan of the vertices, and is the distance between the plane and the cylindrical sides. The top window has the same form as for the LGC design. The figures show that the internal glare on the side windows decreases as the side displacement is increased. The figures show no presence of internal glare on the side windows for displacement larger than 4 inches.

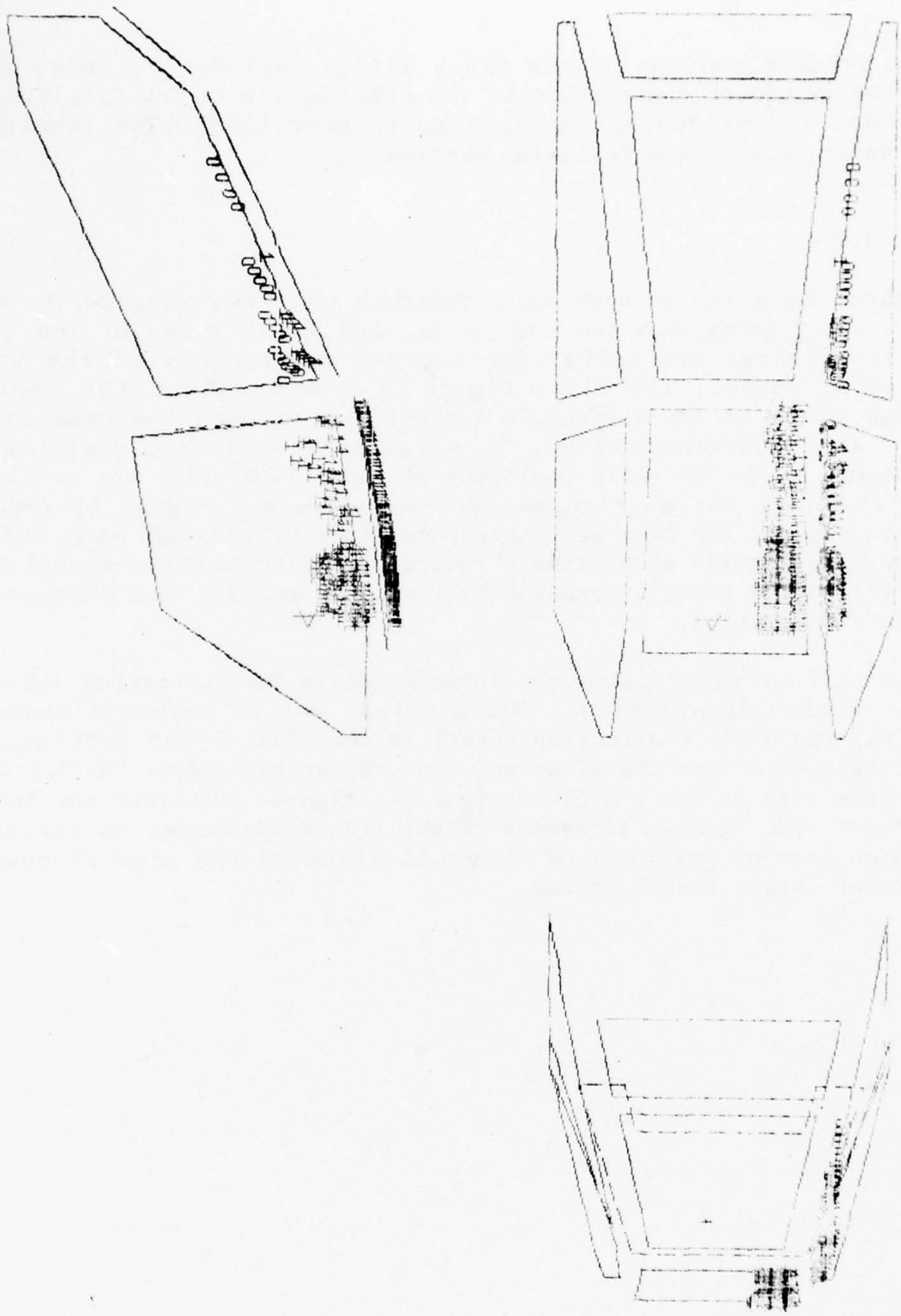

Figure 1a. Primary reflection points for 0.5 inch side window displacement, top window present design, 2^o by 2^o viewing increment.

Figure 1b. Entry positions for reflected rays of Figure 1a.

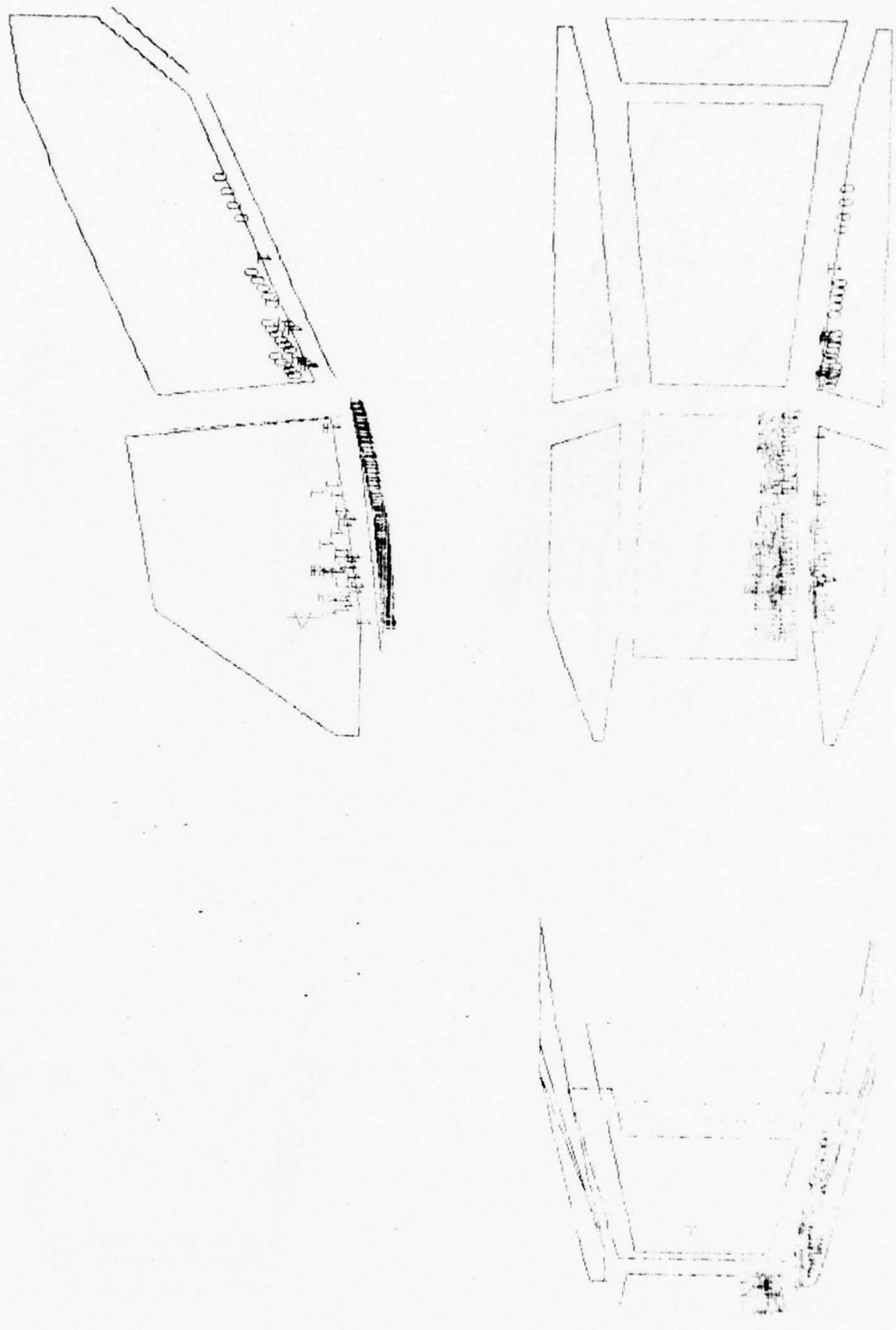

Figure 2a. Primary reflection points for 1.0 inch side window displacement, top window present design, 2^{o} by 2^{o} viewing increment.

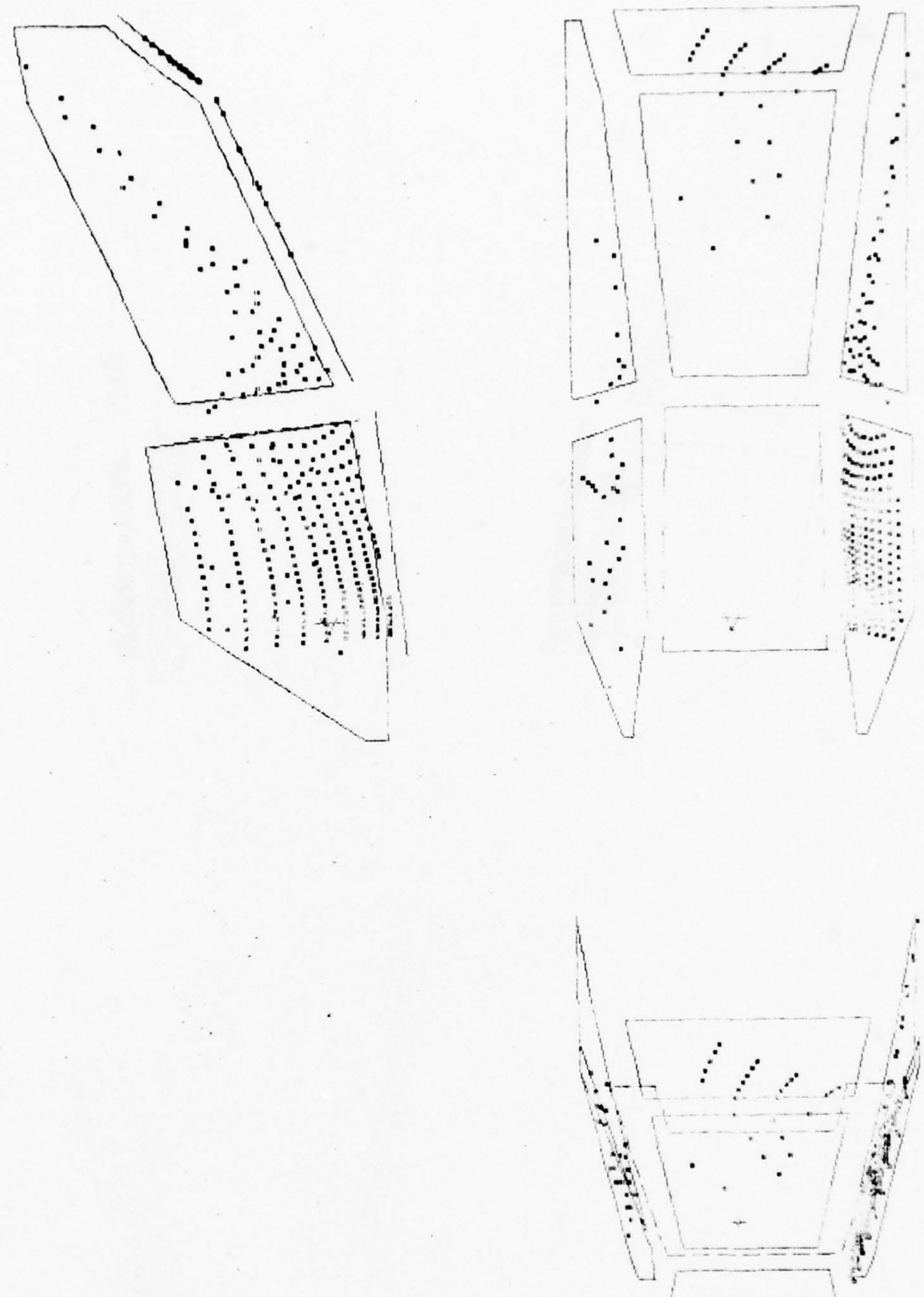

Figure 2b. Entry positions for reflected rays of Figure 2a.

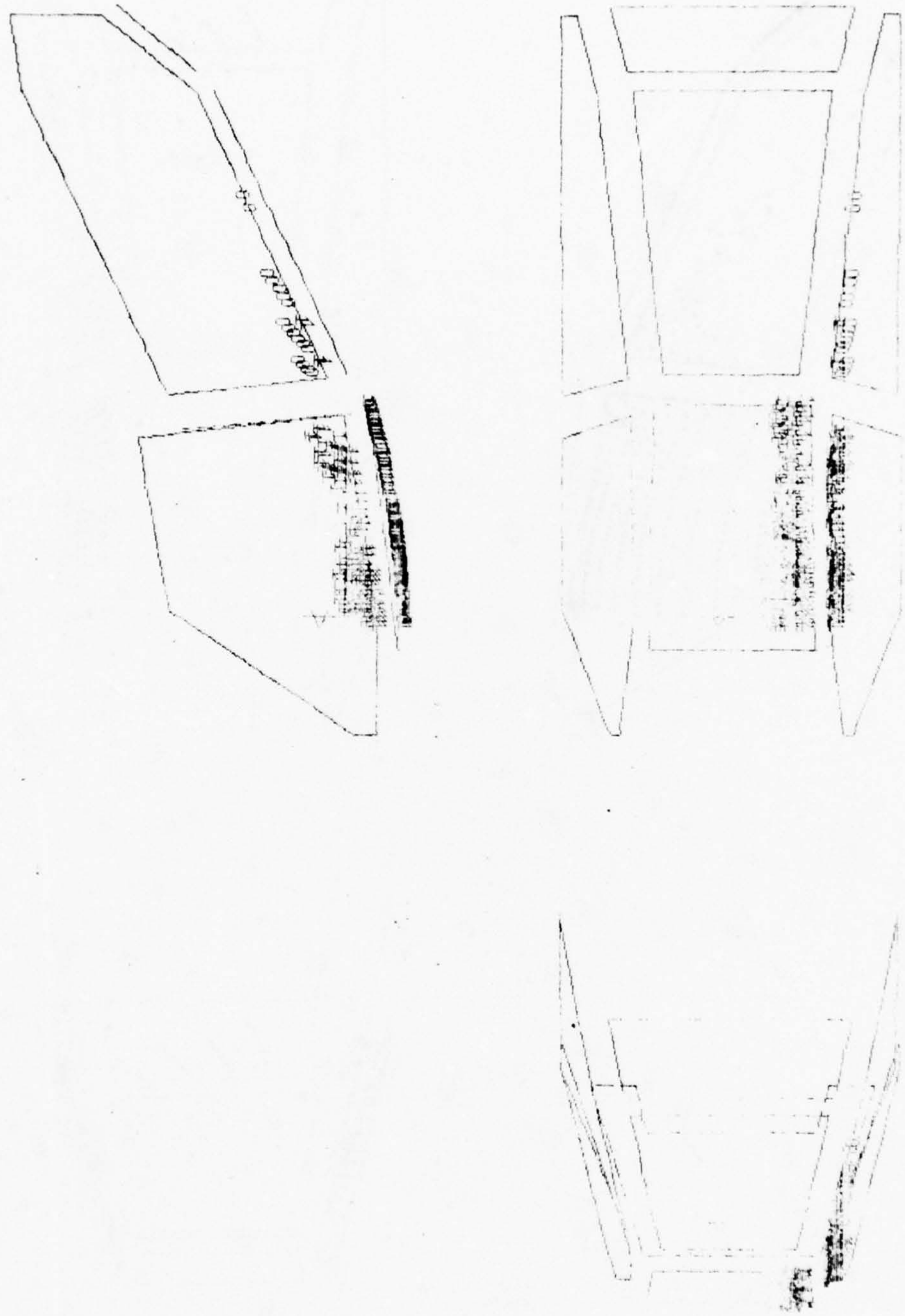

Figure 3a. Primary reflection points for 1.5 inch side window displacement, top window present design, 2° by 2° viewing increment.

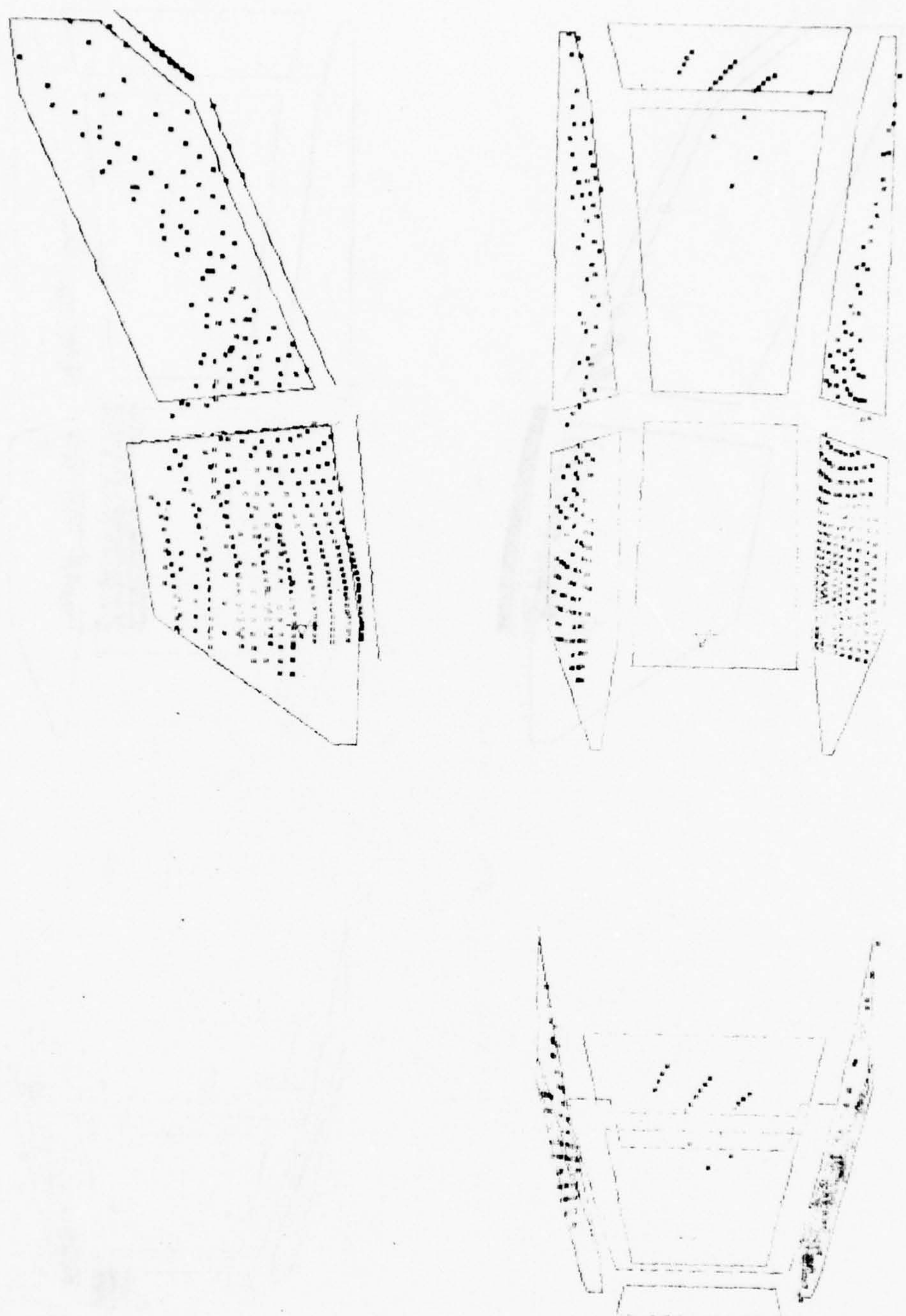

Figure 3b. Entry positions for reflected rays of Figure 3a.

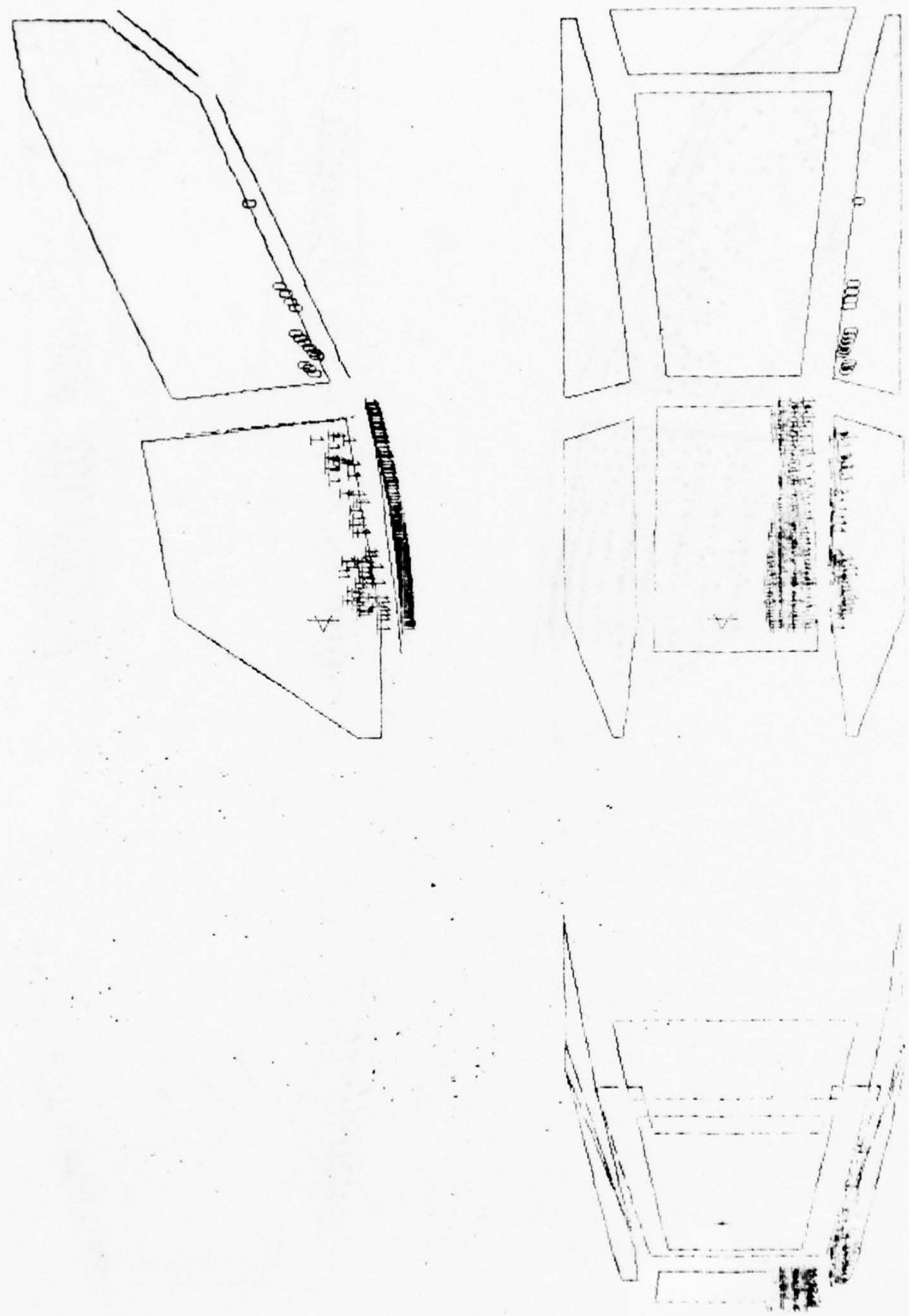

Figure 4a. Primary reflection points for 2.0 inch side window displacement, top window present design, 2^{o} by 2^{o} viewing increment.

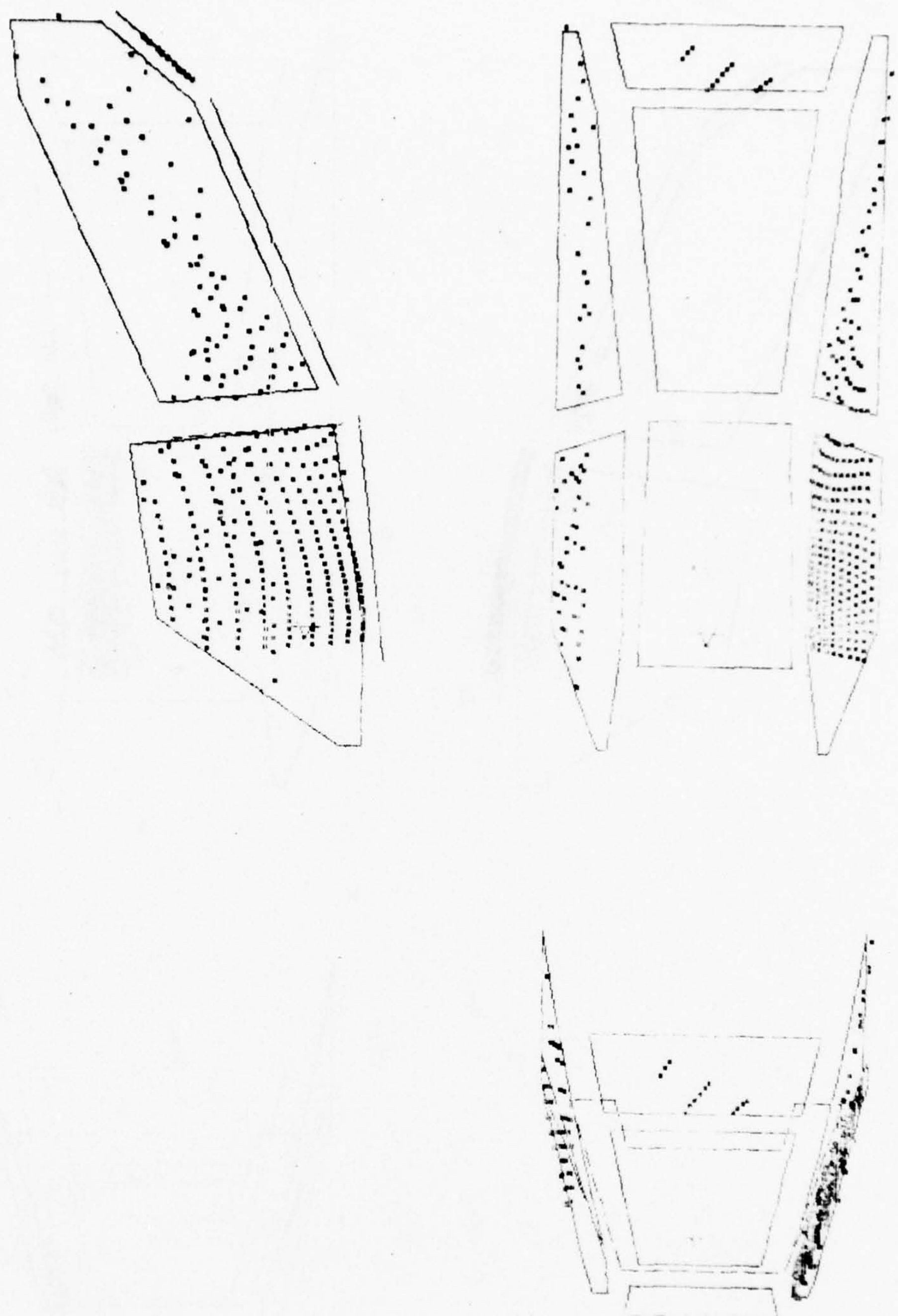

Figure 4b. Entry positions for reflected rays of Figure 4a.

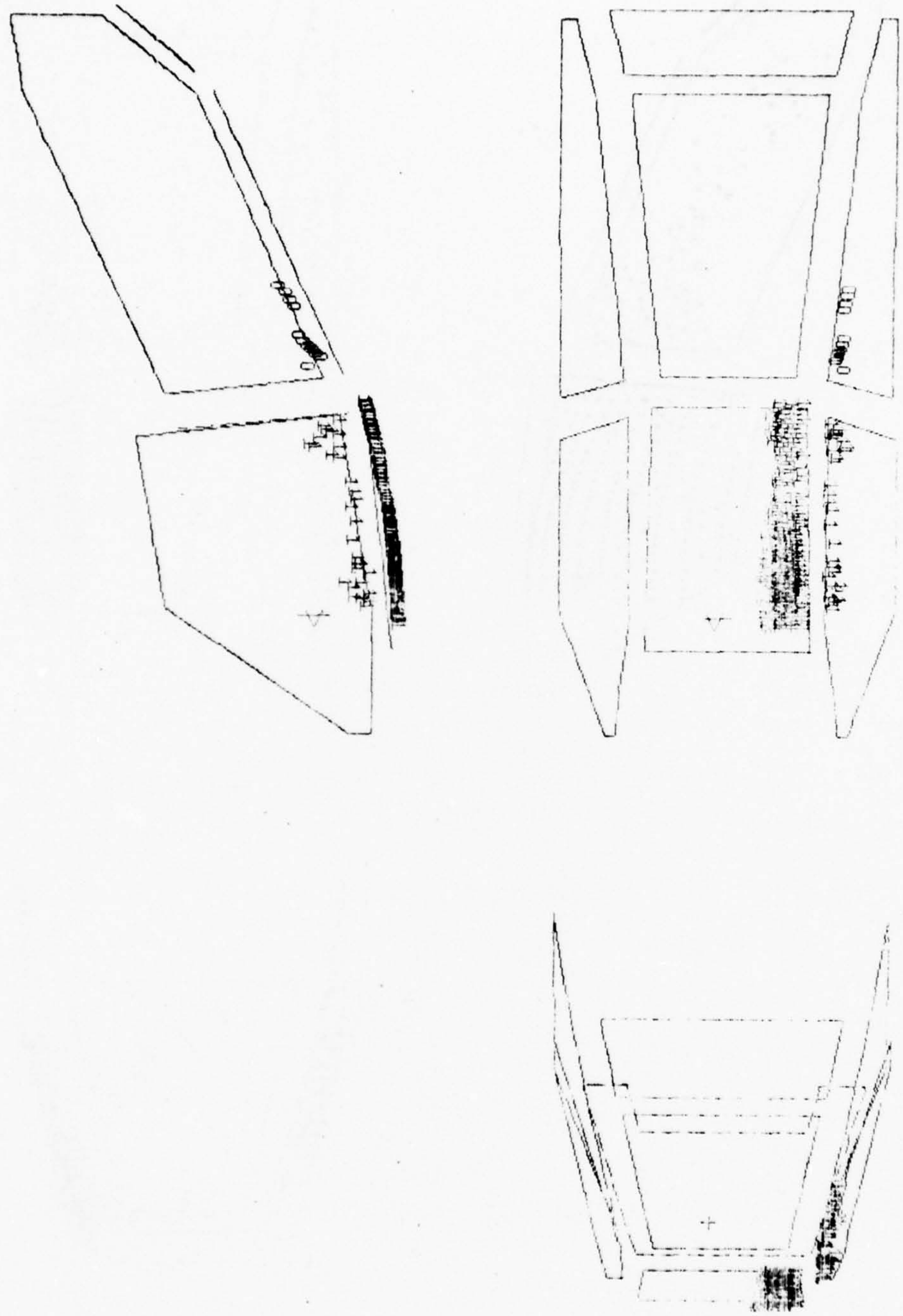

Figure 5a. Primary reflection points for 2.5 inch side window displacement, top window present design, 2^{o} by 2^{o} viewing increment.

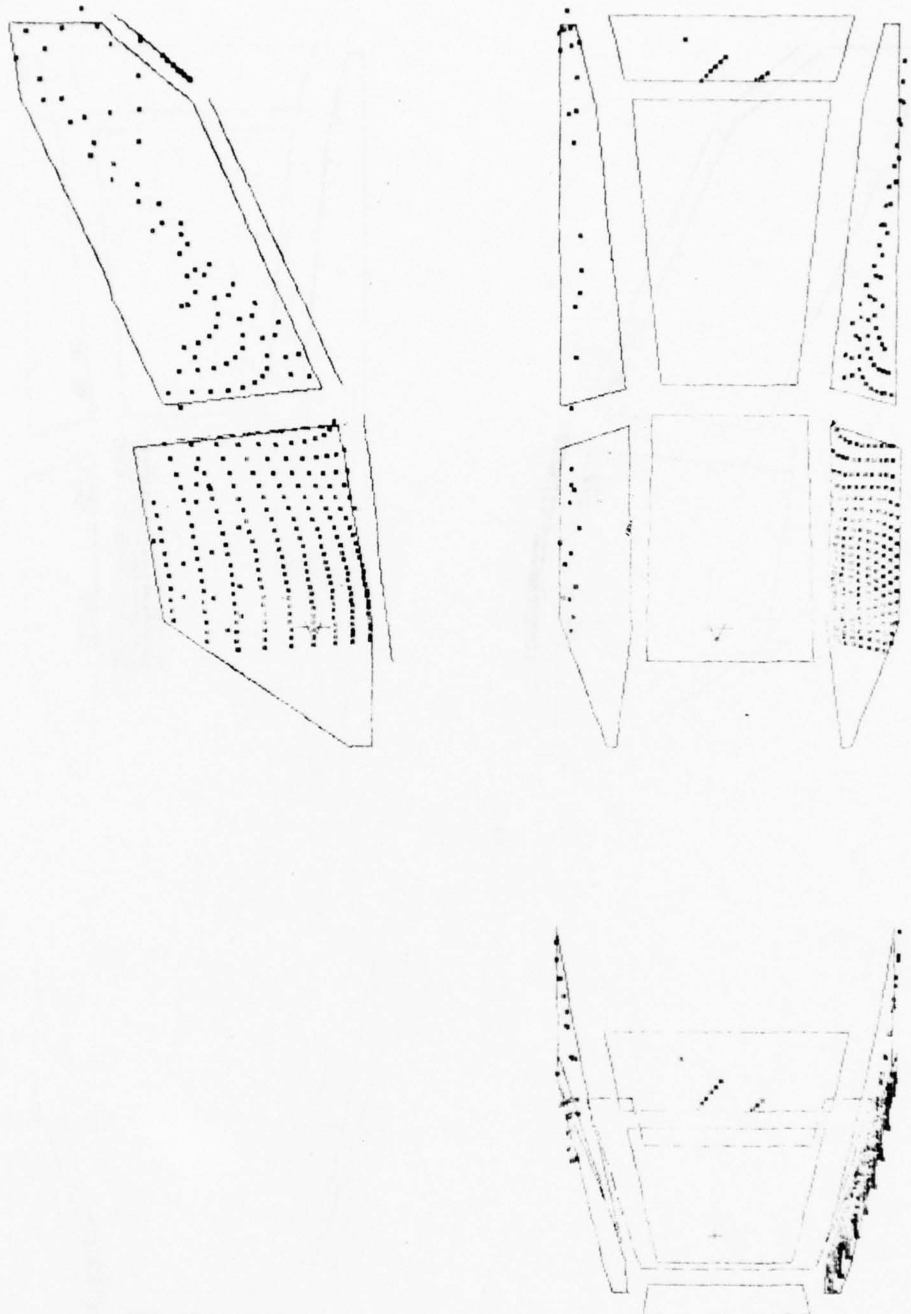

Figure 5b. Entry positions for reflected rays of Figure 5a.

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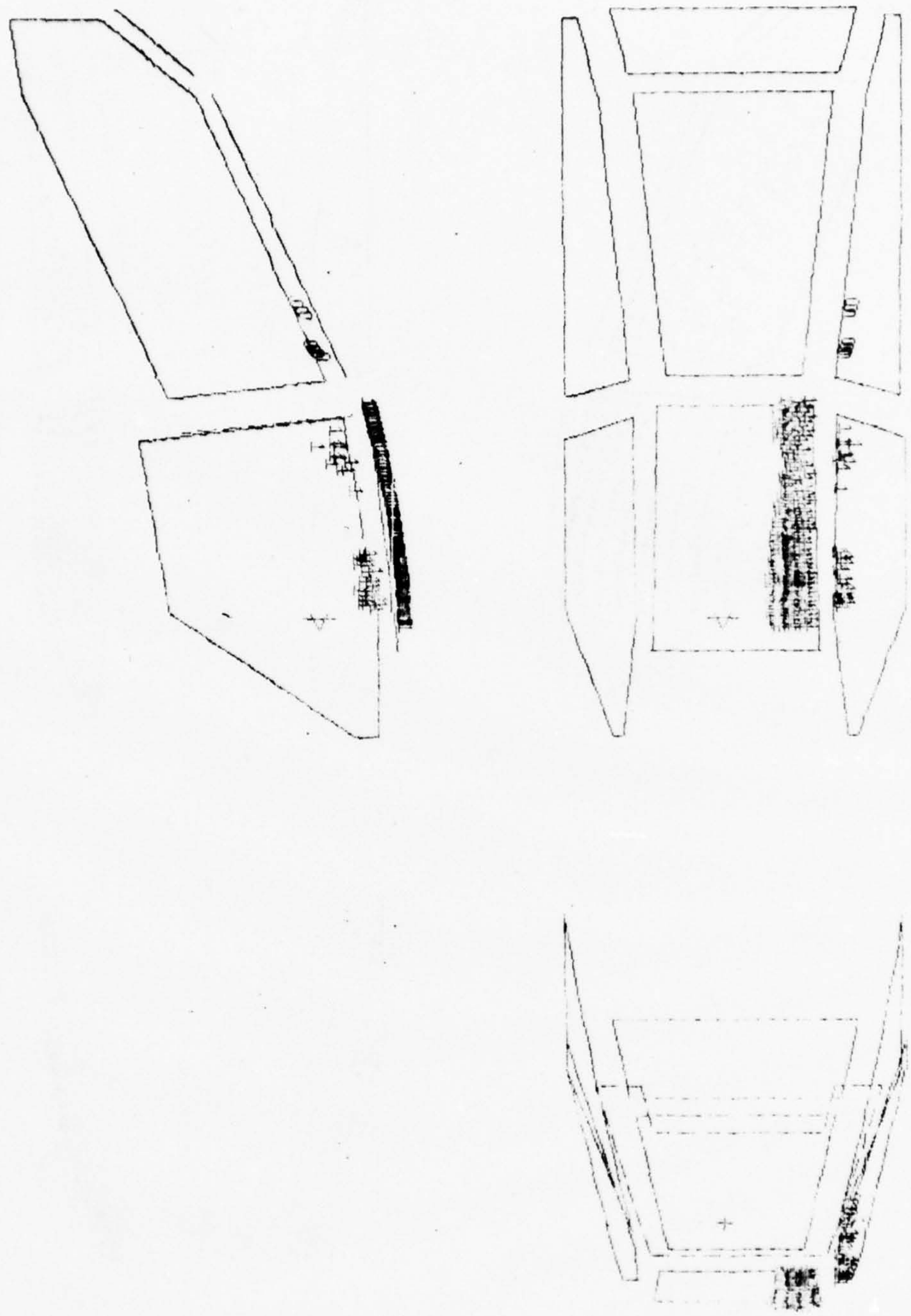


Figure 6a. Primary reflection points for 3.0 inch side window displacement, top window present design, 2^{o} by 2^{o} viewing increment.

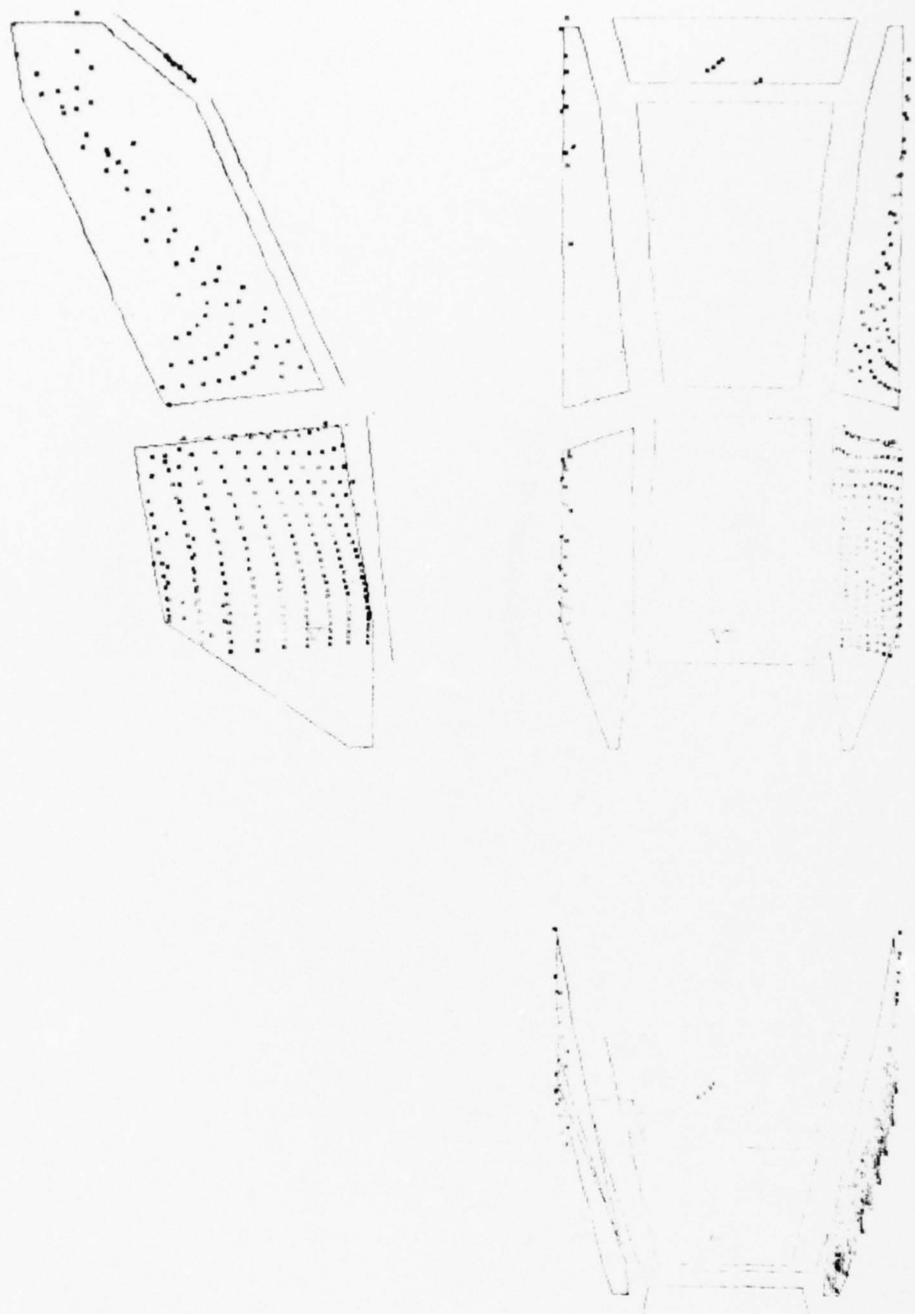


Figure 6b. Entry positions for reflected rays of Figure 6a.

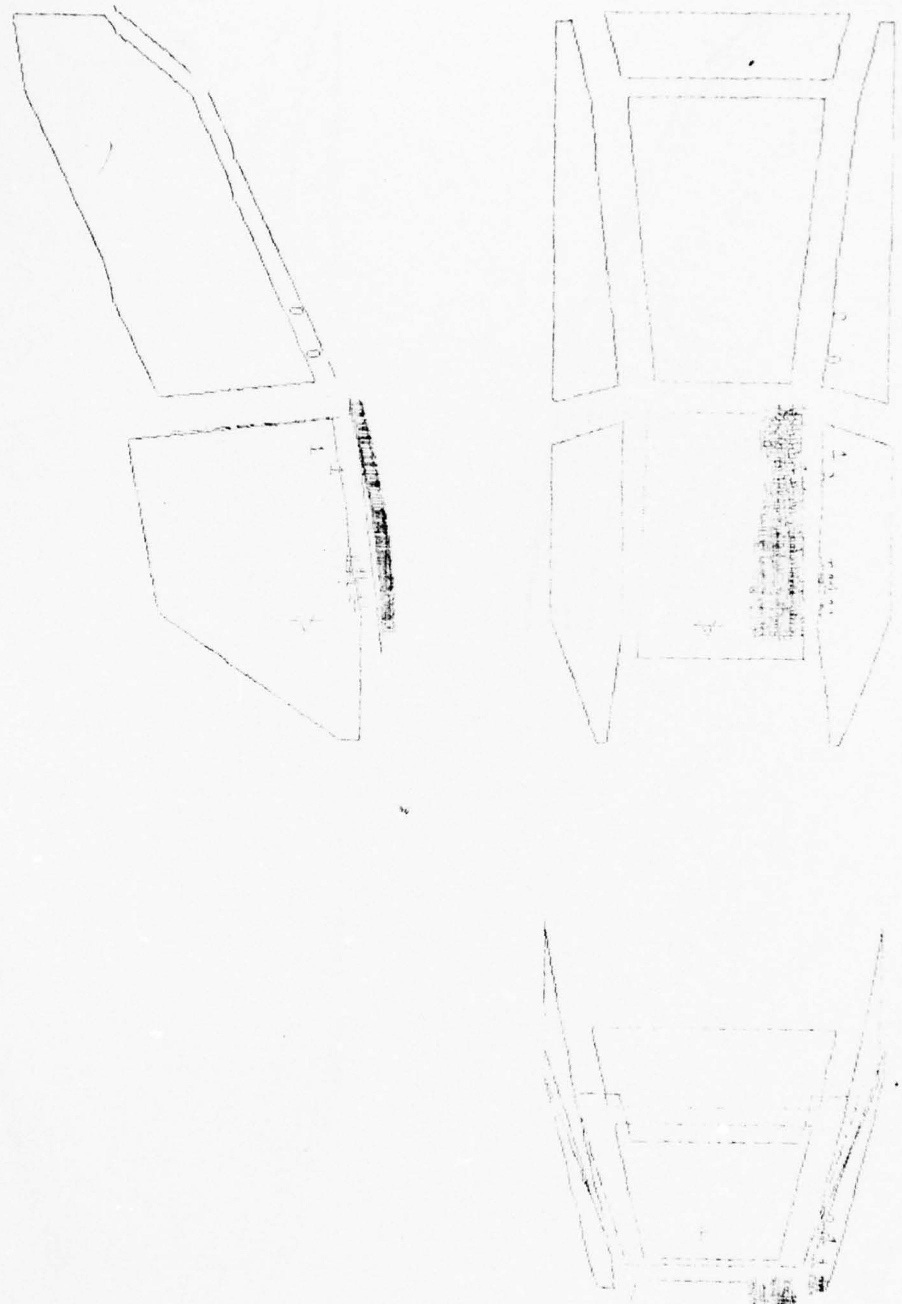


Figure 7a. Primary reflection points for 3.5 inch side window displacement, top window present design, 2° by 2° viewing increment.

Figure 7b. Entry positions for reflected rays of Figure 7a.

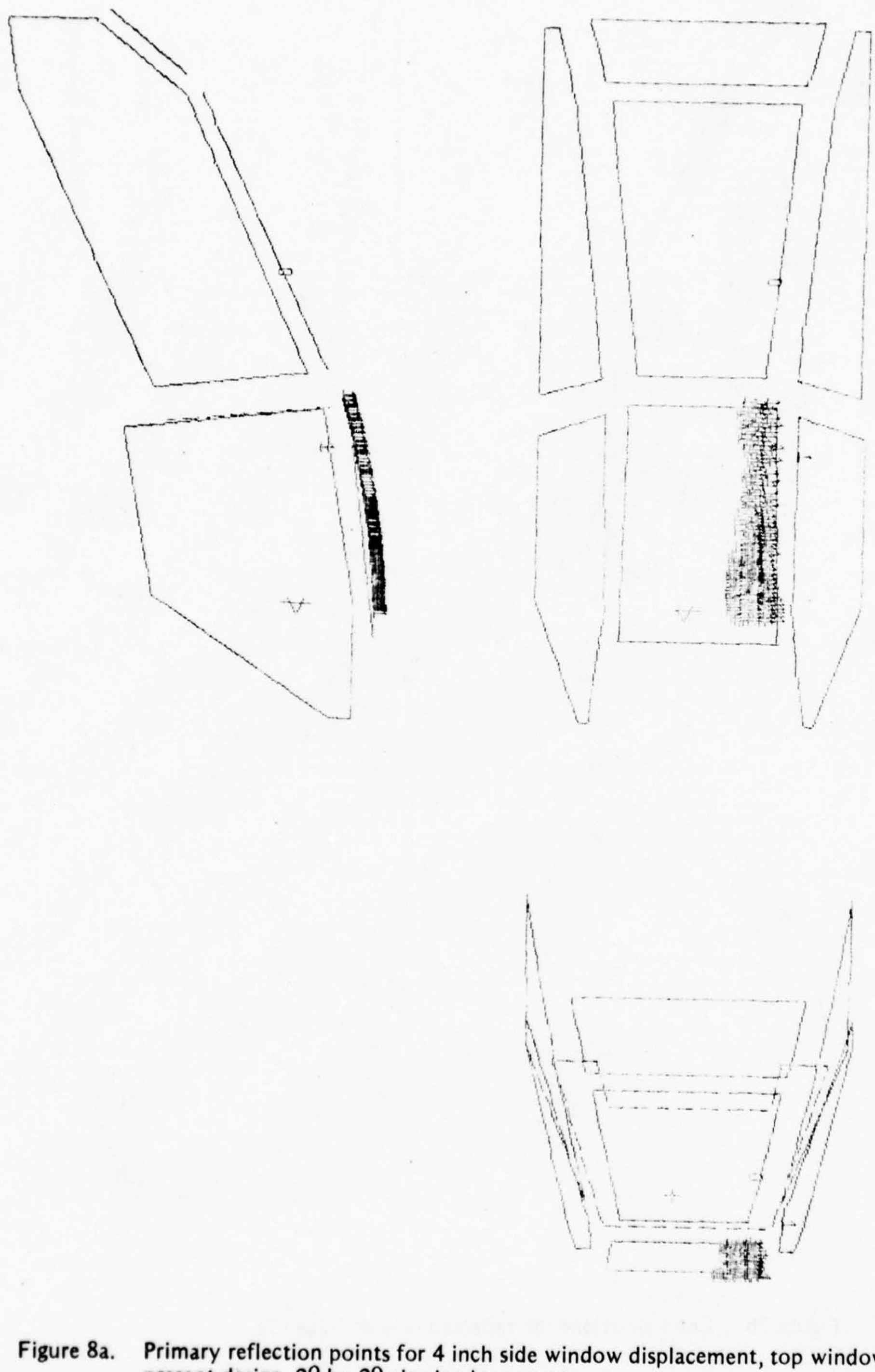


Figure 8a. Primary reflection points for 4 inch side window displacement, top window present design, 2^{o} by 2^{o} viewing increment.

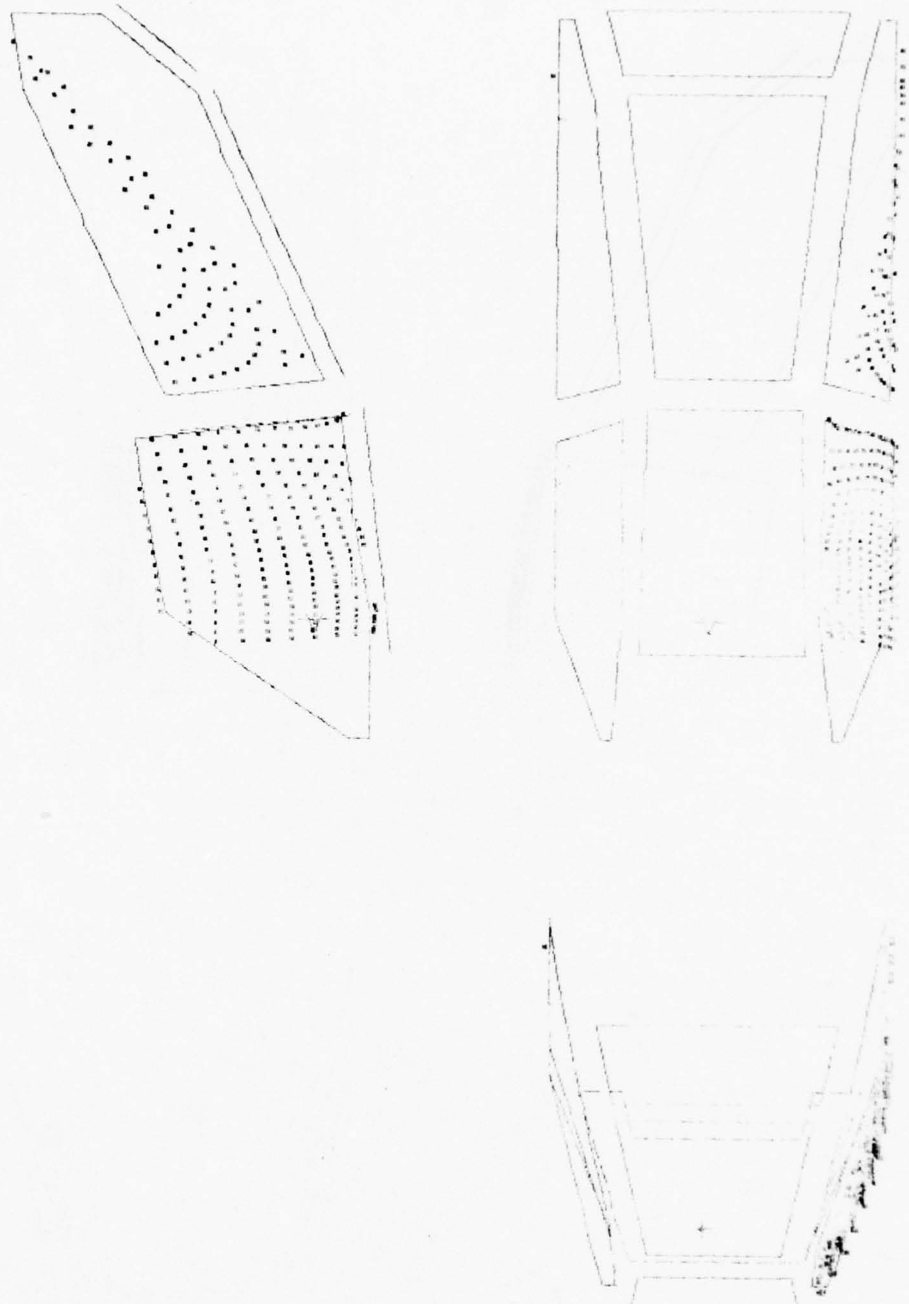


Figure 8b. Entry positions for reflected rays of Figure 8a.

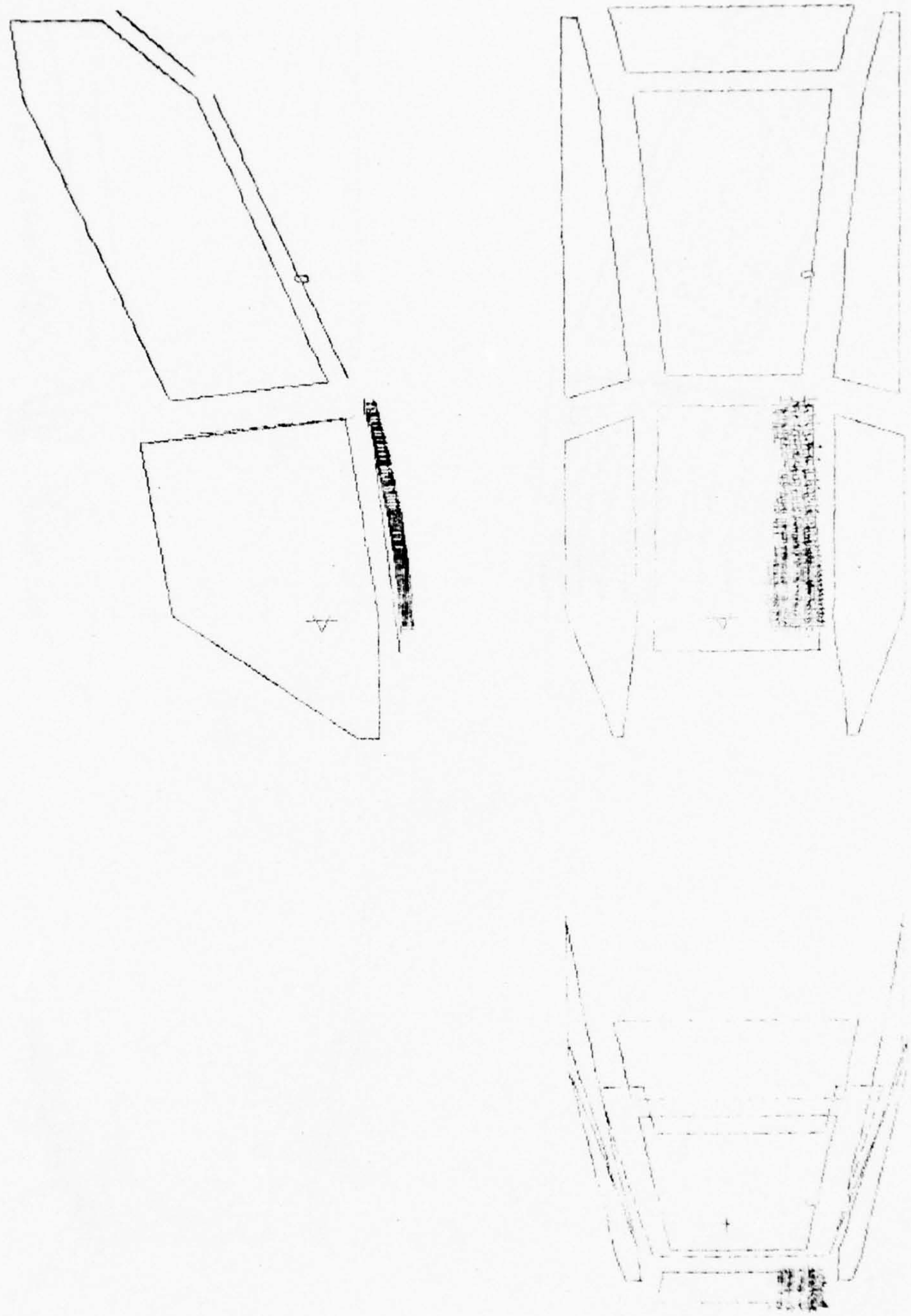


Figure 9a. Primary reflection points for 4.5 inch side window displacement, top window present design, 2° by 2° viewing increment.

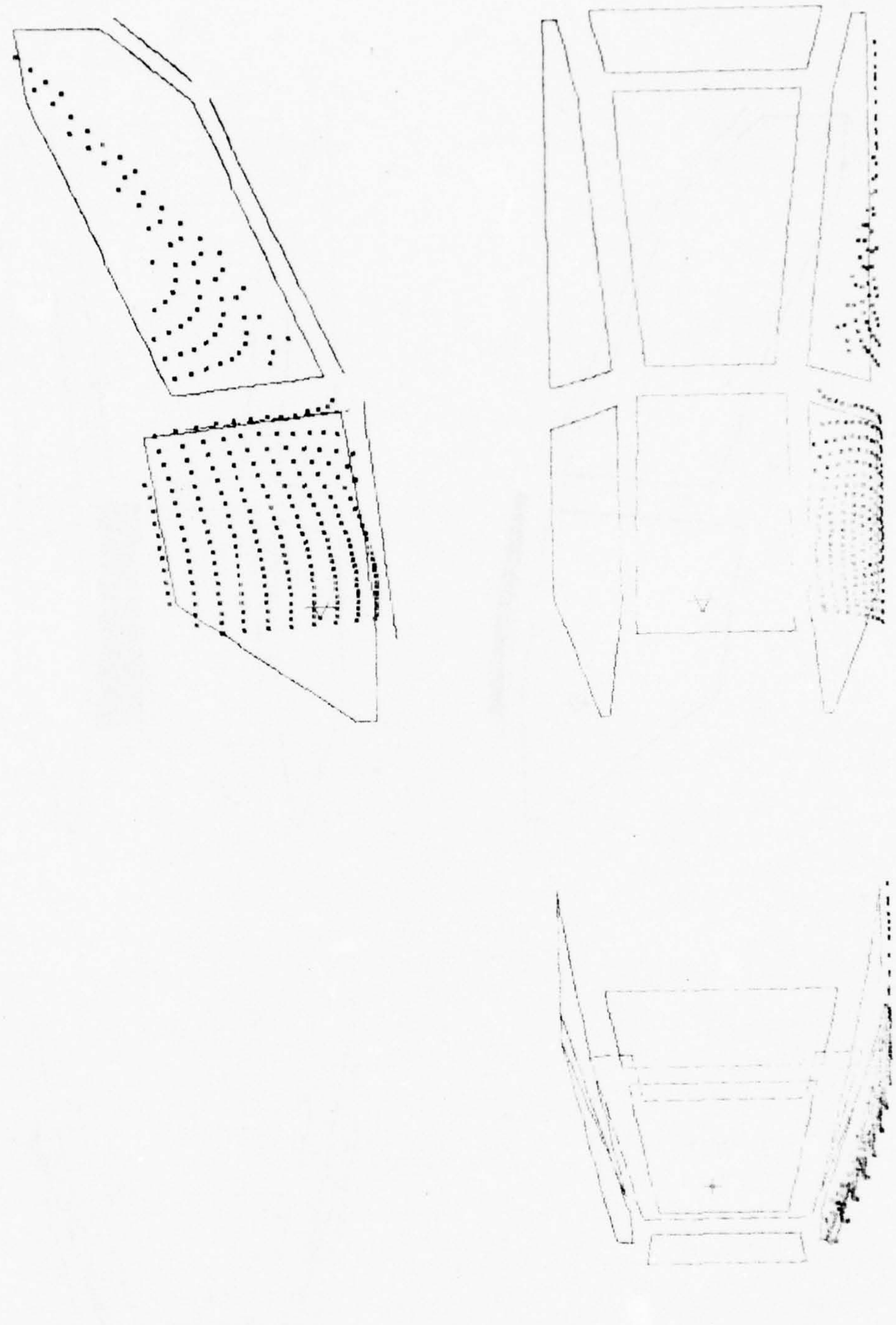


Figure 9b. Entry positions for reflected rays of Figure 9a.

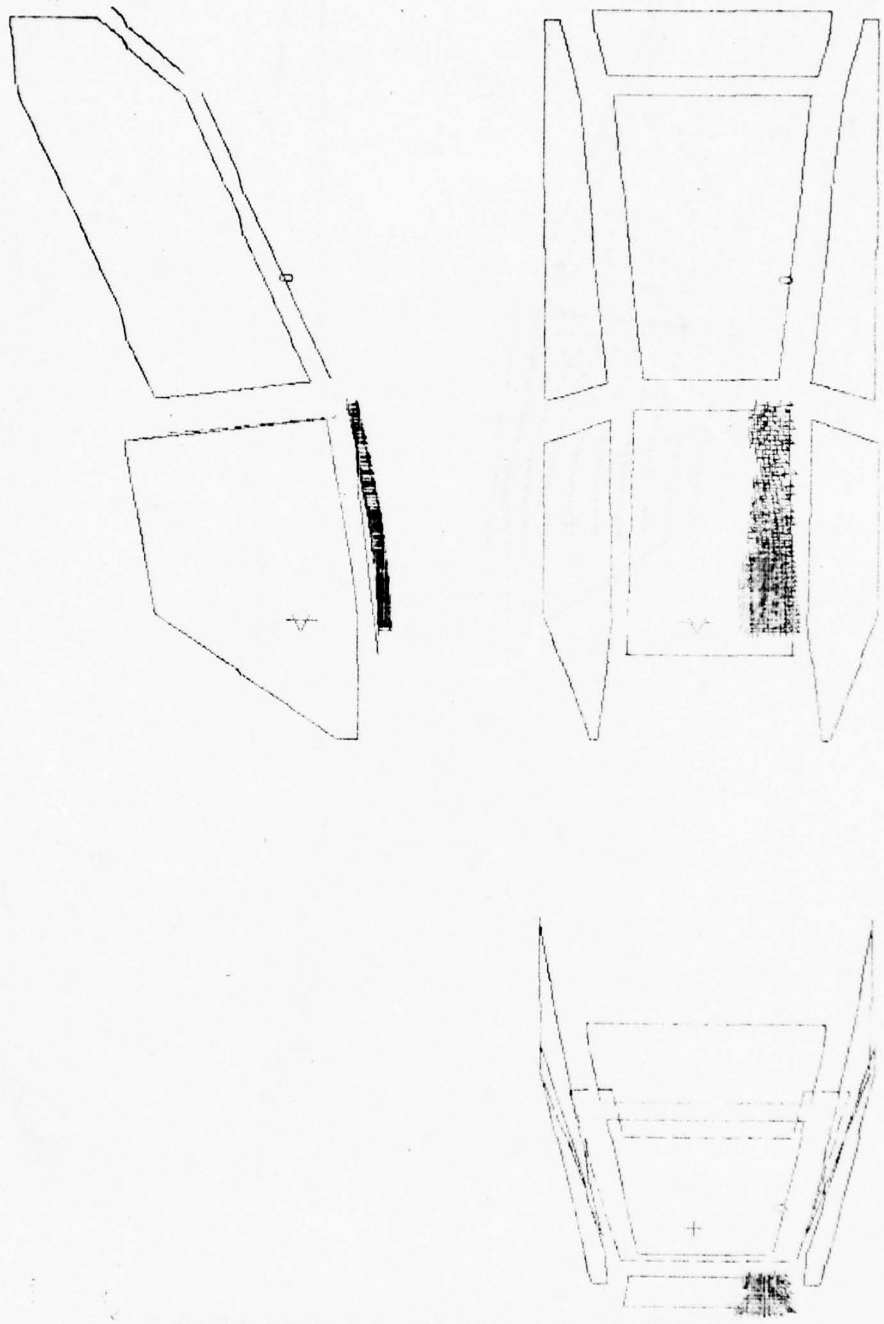


Figure 10a. Primary reflection points for 5.0 inch side window displacement, top window present design, 2° by 2° viewing increment.

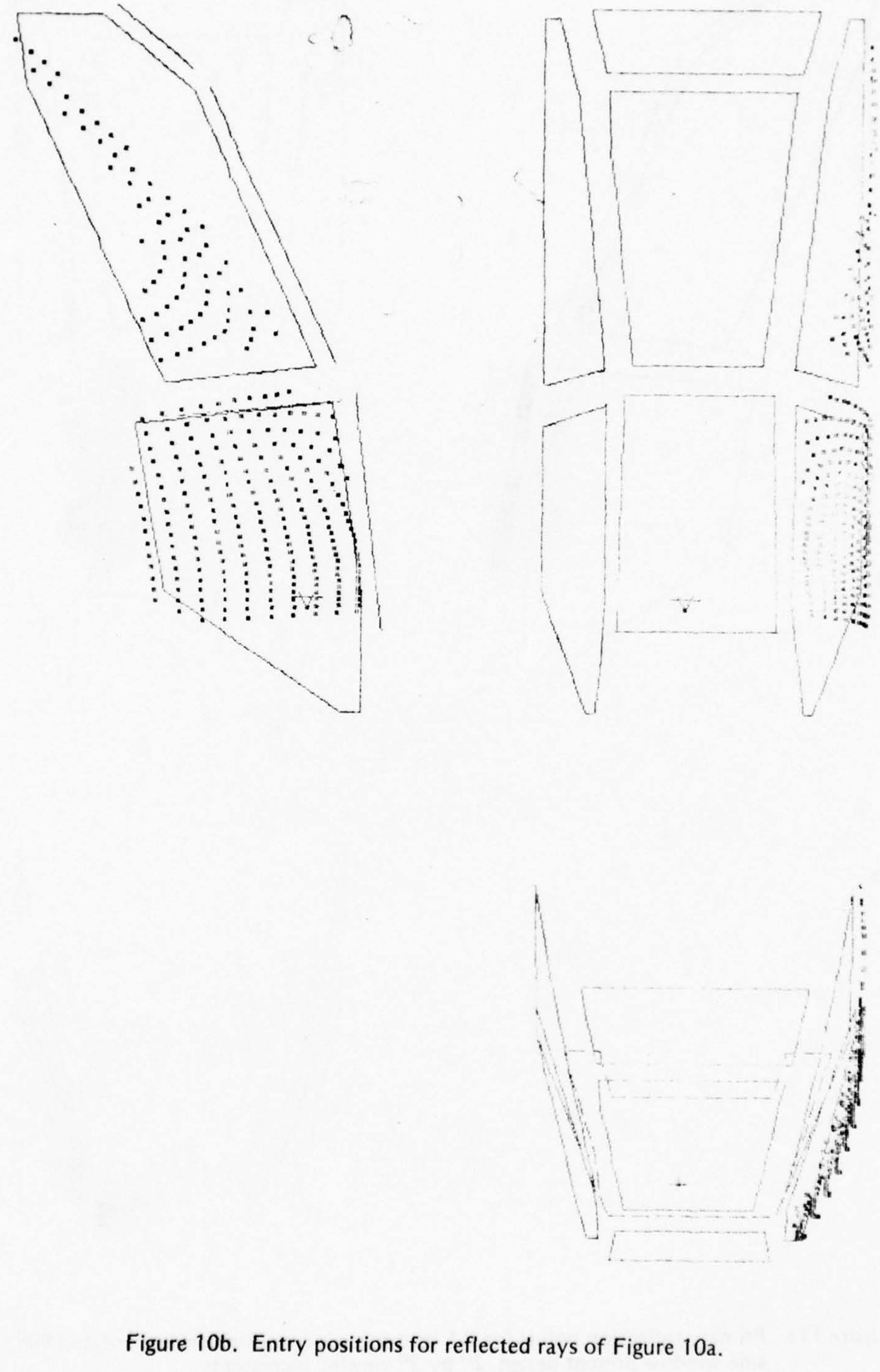


Figure 10b. Entry positions for reflected rays of Figure 10a.

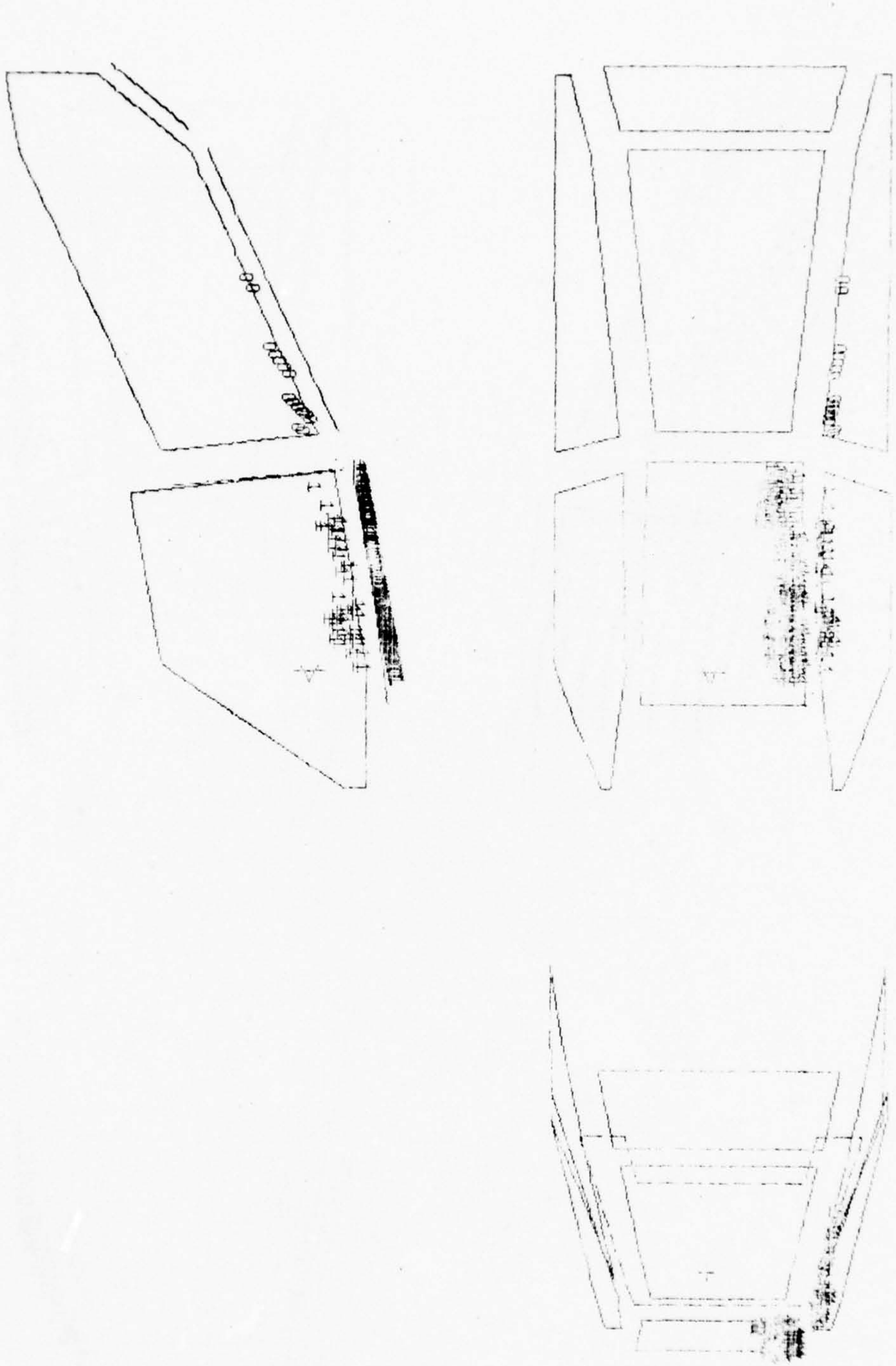


Figure 11a. Primary reflection points for 0.5 inch top window displacement rotated 90°, side window present design, 2° by 2° viewing increments.

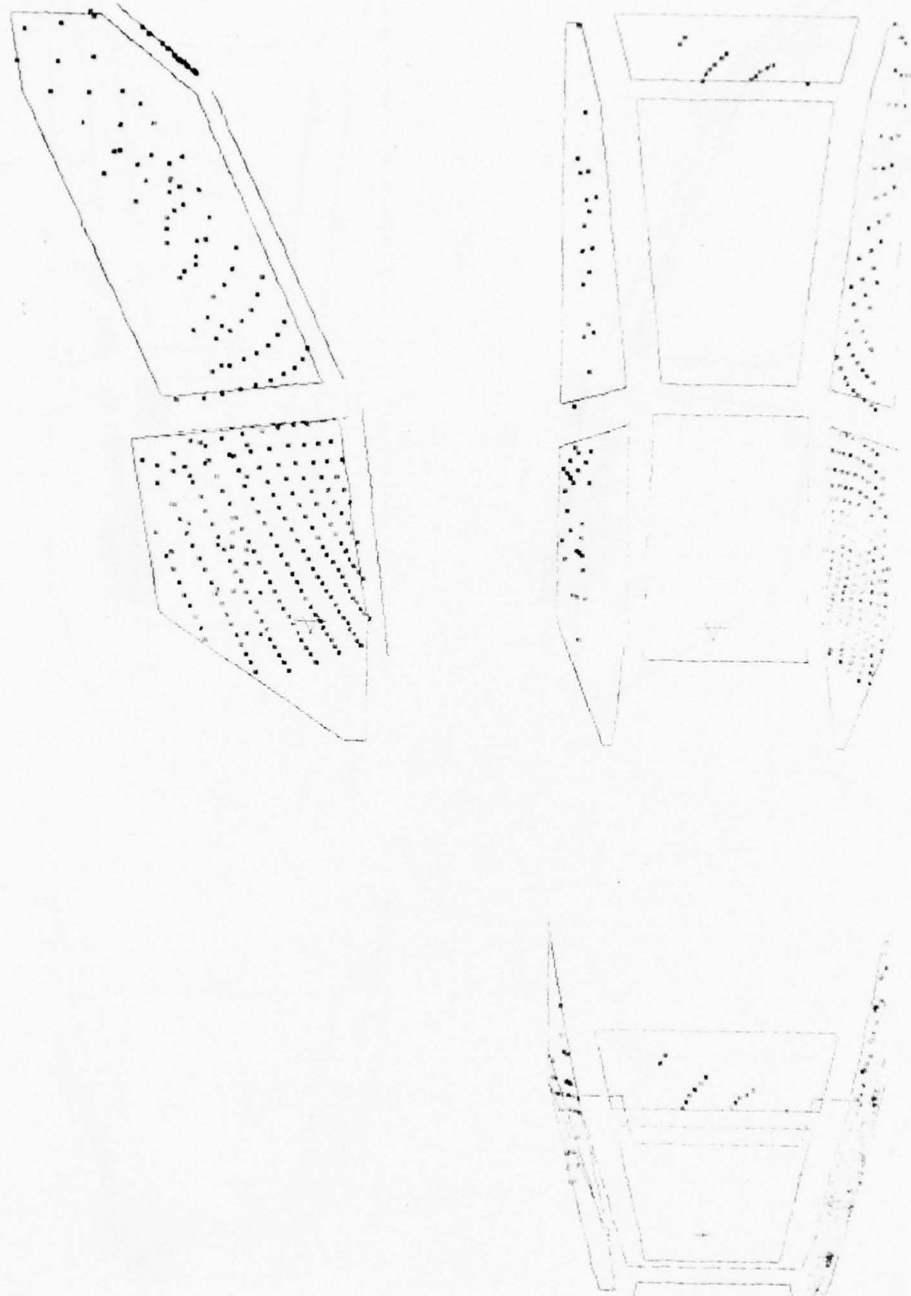


Figure 11b. Entry positions for reflected rays of Figure 11a.

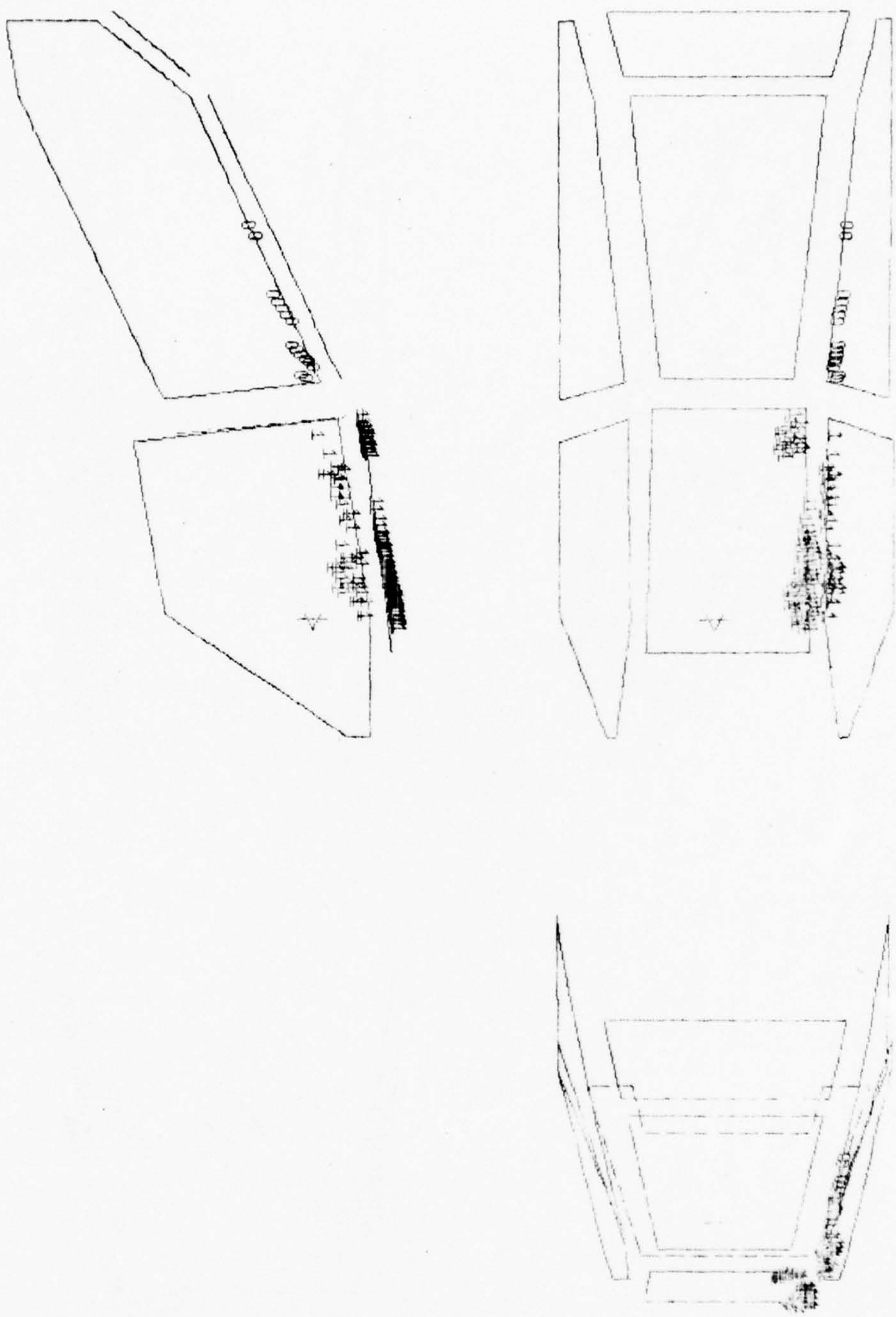


Figure 12a. Primary reflection points for 1.0 inch top window displacement rotated 90°, side window present design, 2° by 2° viewing increment.

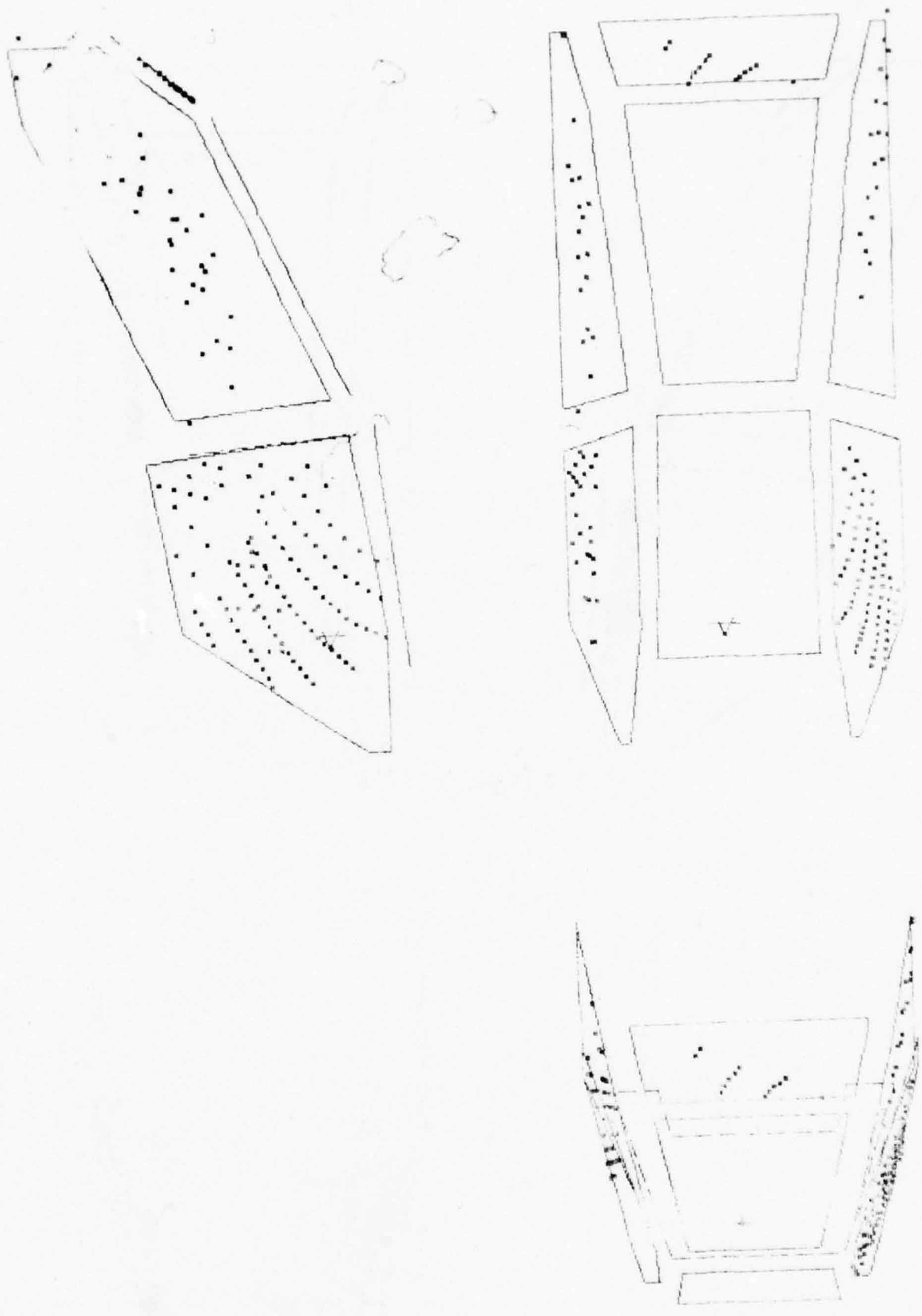


Figure 12b. Entry positions for reflected rays of Figure 12a.

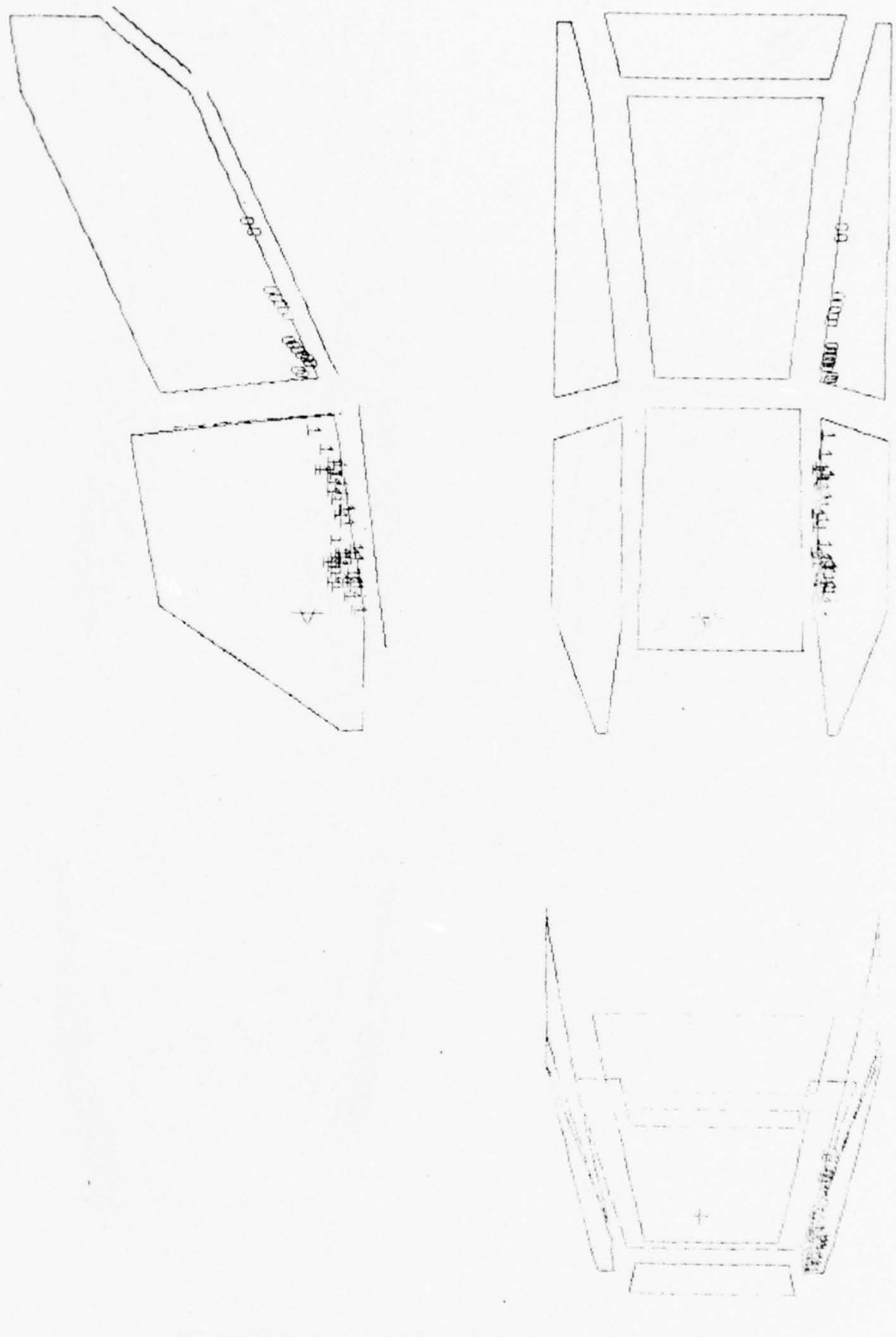


Figure 13a. Primary reflection points for 1.5 inch top window displacement rotated 90°, side window present design, 2° by 2° viewing increments.

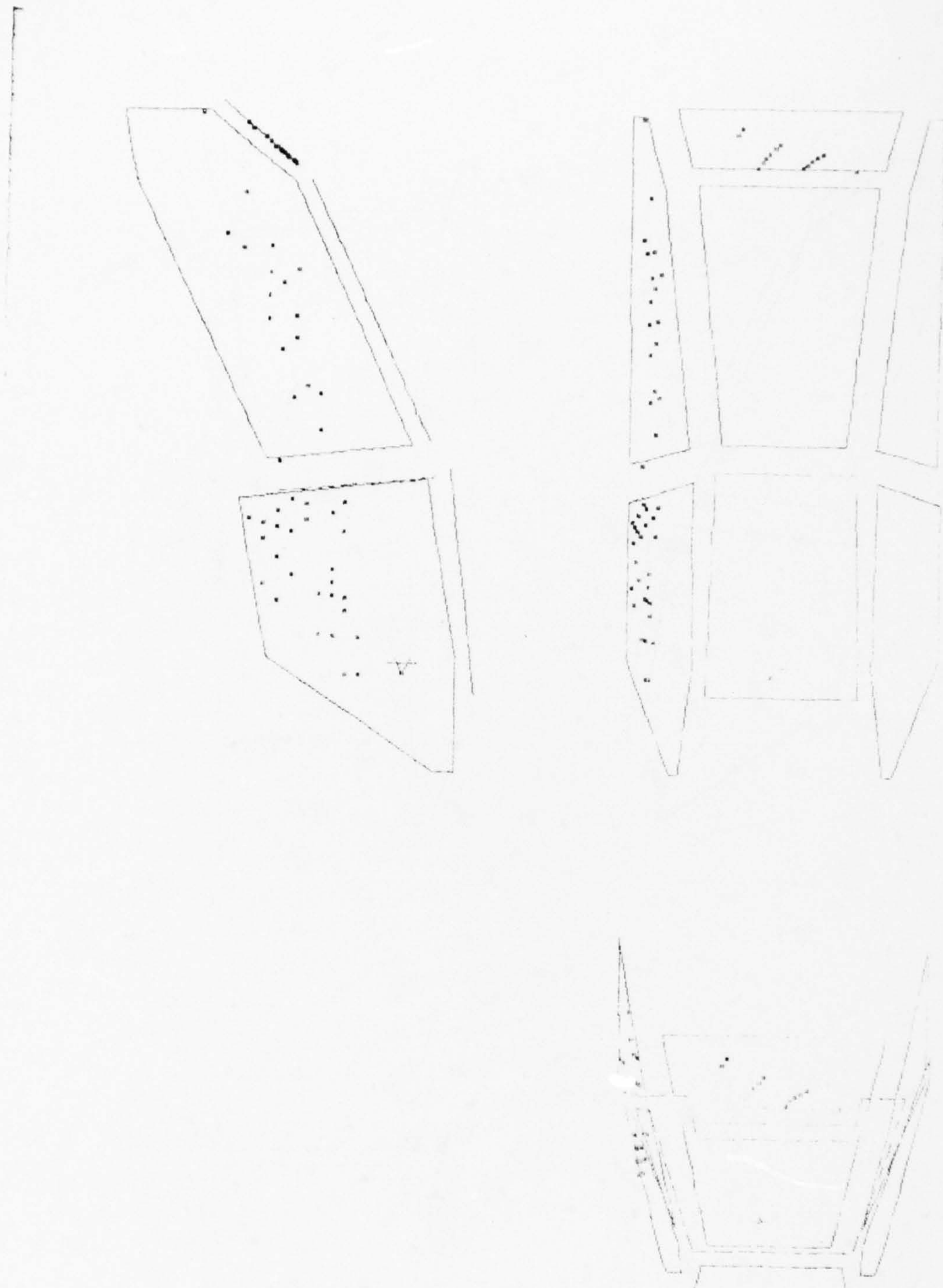


Figure 13b. Entry positions for reflected rays of Figure 13a.

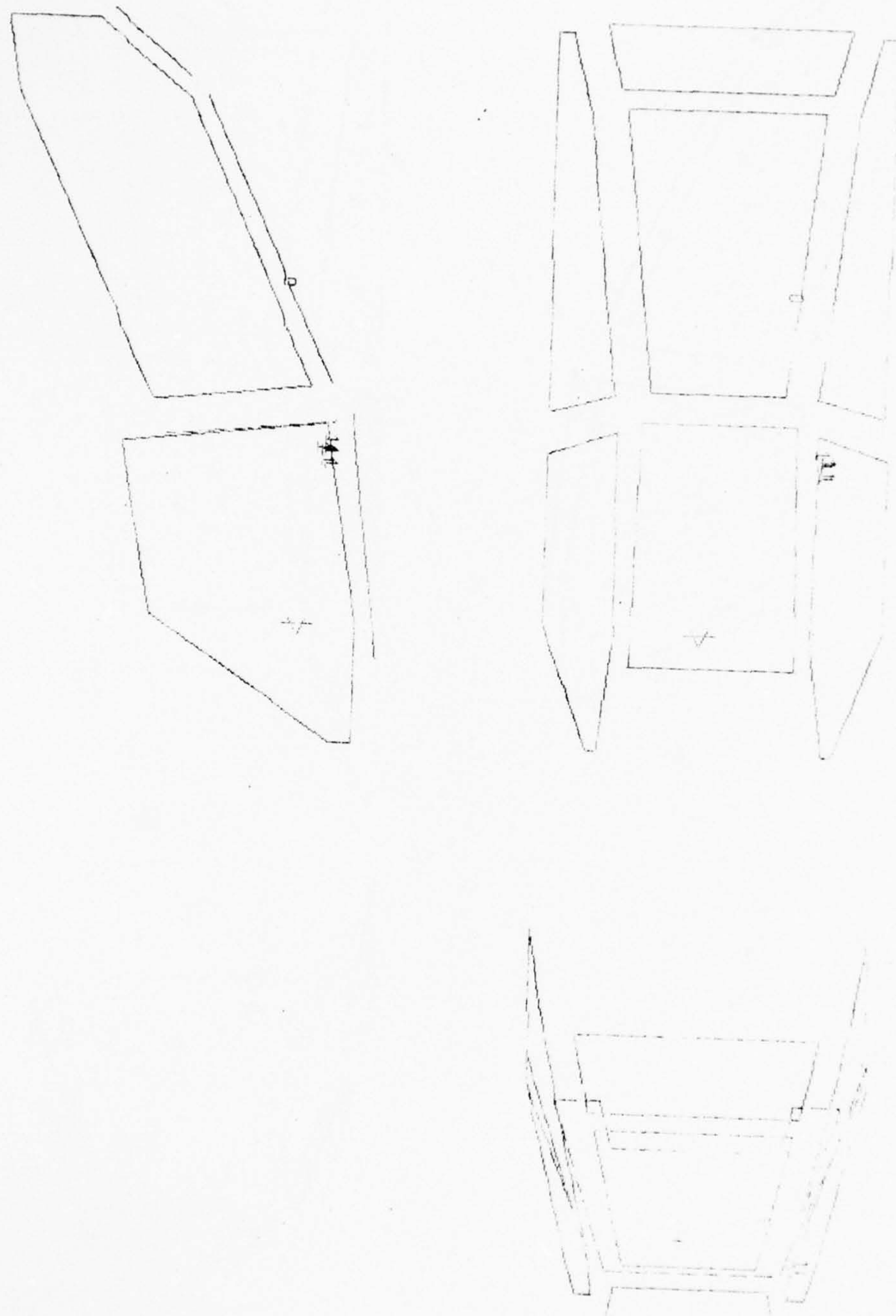


Figure 14a. Primary reflection points for 4.0 inch side window displacement, 1.5 inch top window displacement rotated 90°, 0.5° by 0.5° viewing increment.

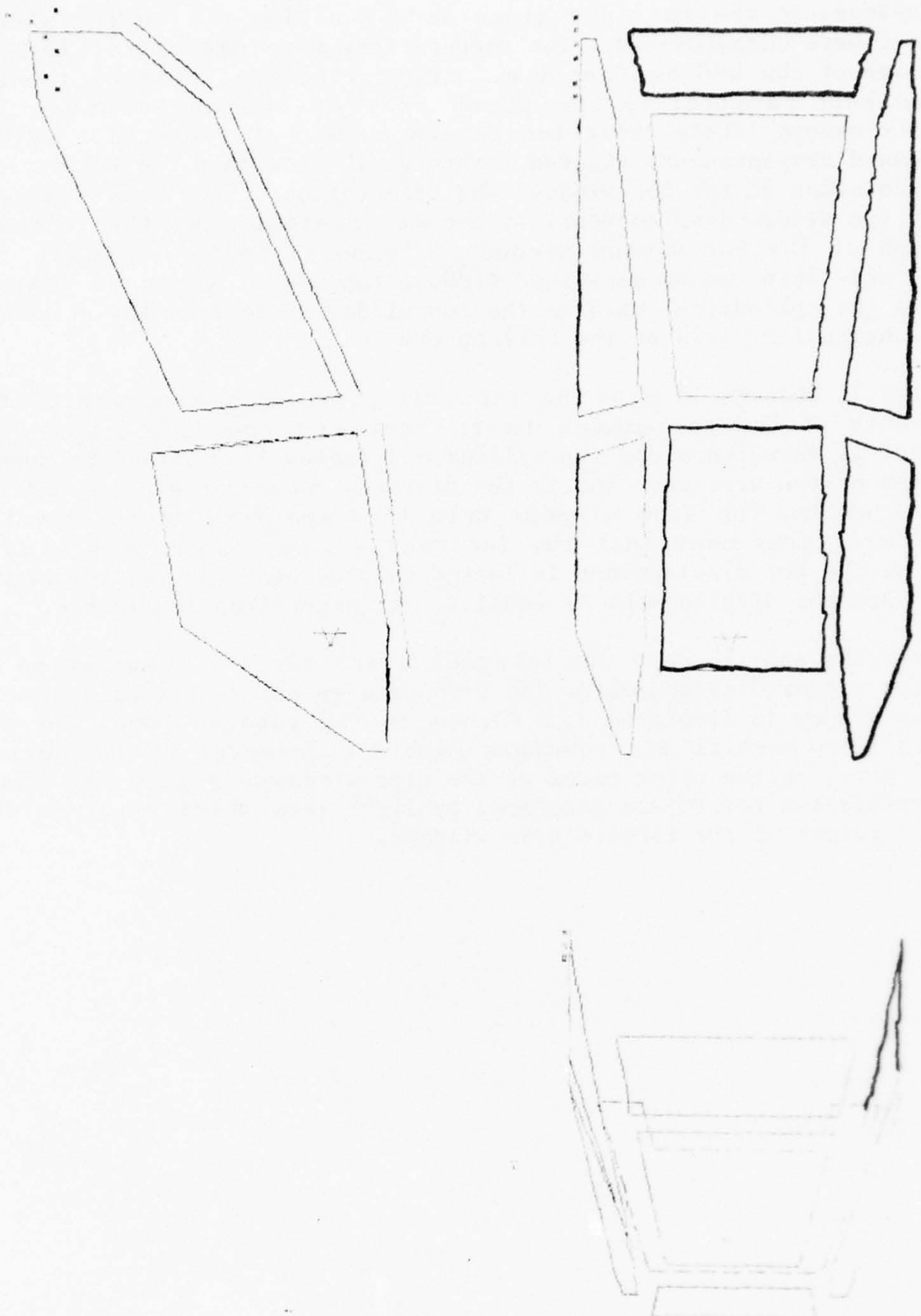


Figure 14b. Entry positions for reflected rays of Figure 14a.

The changes in the internal glare as a function of the top window displacement were computed next. The computations were made first for the configuration of the LGC design; i.e., the cylindrical axis of the top window was kept parallel to the pitch axis of the helicopter. The computations showed little reduction in the number of reflection points with increased displacement. Figures 1 through 10 show that the reflections occur on the sides of the top window. The orientation of the sides was not altered by the window displacement. It became apparent that the left and right sides of the top window needed to be bowed in to decrease the internal glare. This was accomplished without the use of compound shapes, by rotating the cylindrical axis of the top window 90-degrees for alignment with the longitudinal axis of the helicopter.

Figures 11 through 13 show the internal glare as a function of the displacements of the top window in the rotated configuration. The displacement is measured along the cylindrical radius in a direction normal to the plane of the vertices, and is the distance between the plane and the cylindrical sides. The side windows have the same form as for the LGC design. The figures show that the internal glare on the top window decreases as the top displacement is increased. The glare on the top window is absent when the displacement is equal to or larger than 1.5 inches.

Figures 14a and 14b show the internal glare for one combination of side and top window displacements. The side windows are displaced 4 inches and the top window is displaced 1.5 inches in the rotated mode. The few reflection points which are possible (for a 0.5-degree by 0.5-degree increment) occur on the upper edges of the side windows. Figure 14b shows that the reflection points are generated by light rays which enter at the lower front corner of the forward side windows.

External Glint

The results of the computations for the external glint are shown in Figures 15 through 21. These figures were drawn on a Calcomp plotter which is a perpherial unit of the CDC 7600 computer system used for computations here at the US Army Aberdeen Proving Ground facilities. The figures occur in sets and show the results for various combinations of side and top window displacements. The first figure of a set shows the canopy surface points used in the reflection computations on side, top, and front views of the canopy frames.

The remaining figures of the set show plots of the computed reflected directions for the side windows, the top window and all windows combined. The directions of reflected rays are plotted as points according to their elevation and azimuth angles. Each point on a plot gives the angles for a ray reflected from one of the surface points on the frame sketch. The locus of such points for a specific sun-angle forms a line on a plot. The line shows all of the angles at which solar glint from the window(s) is visible at that sun-angle.

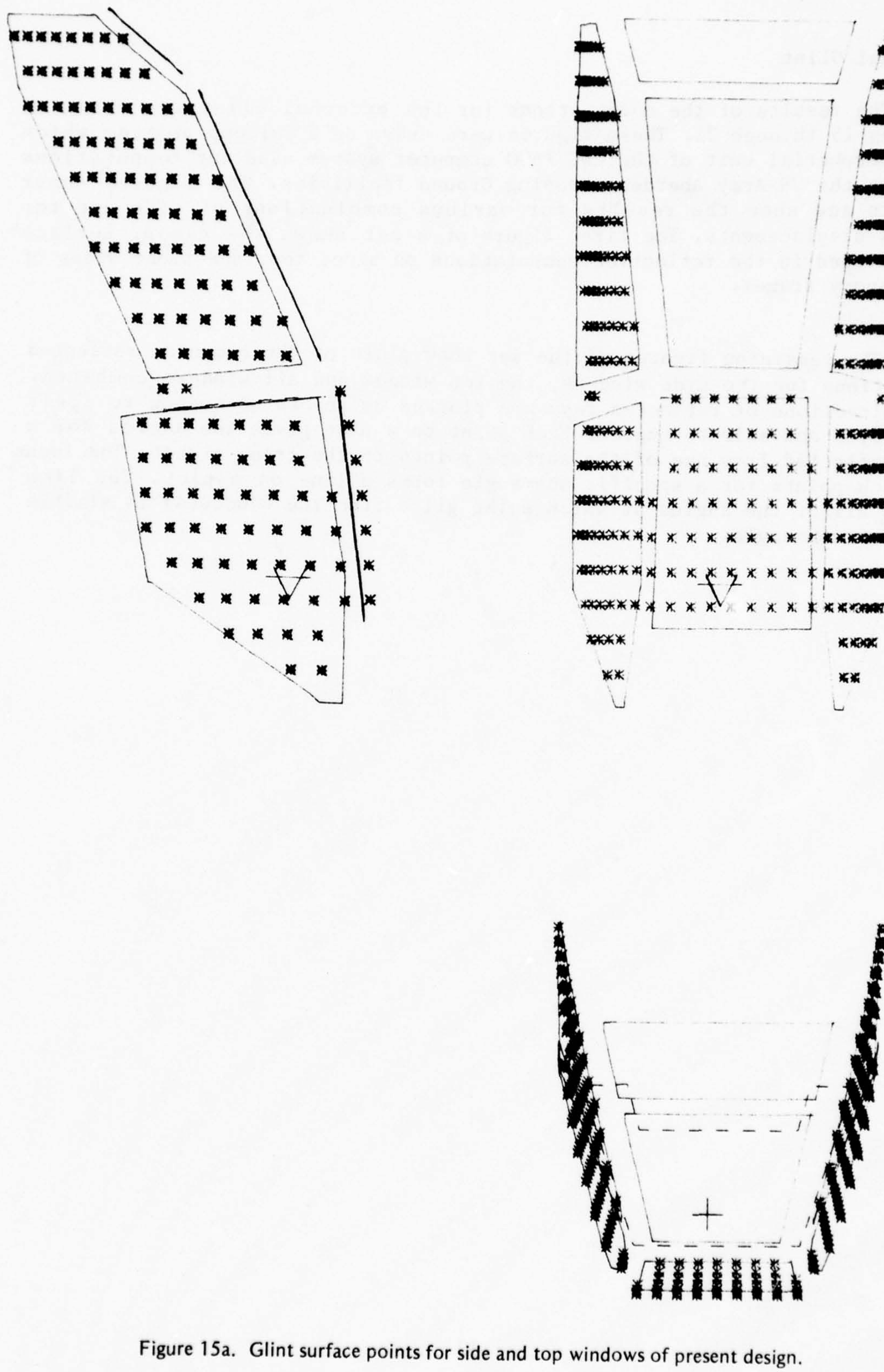
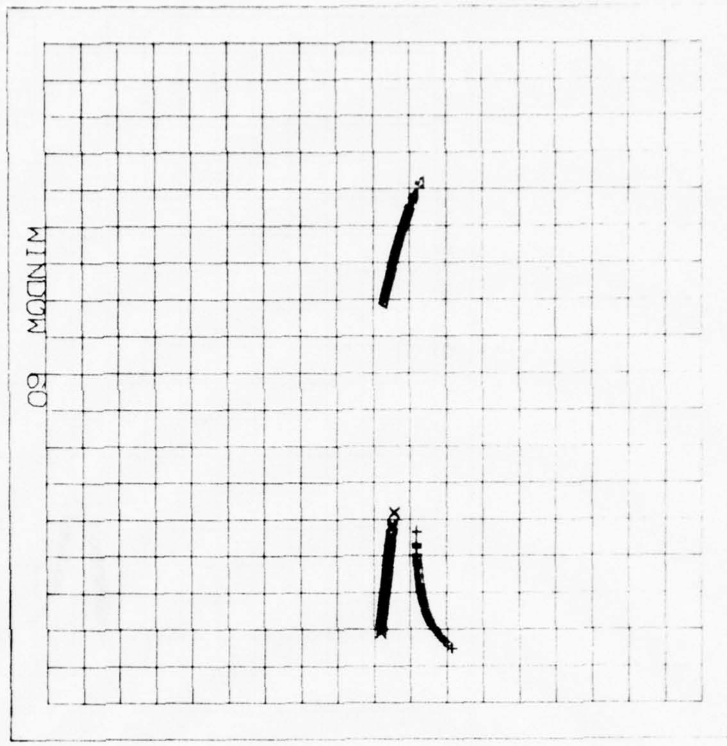


Figure 15a. Glint surface points for side and top windows of present design.



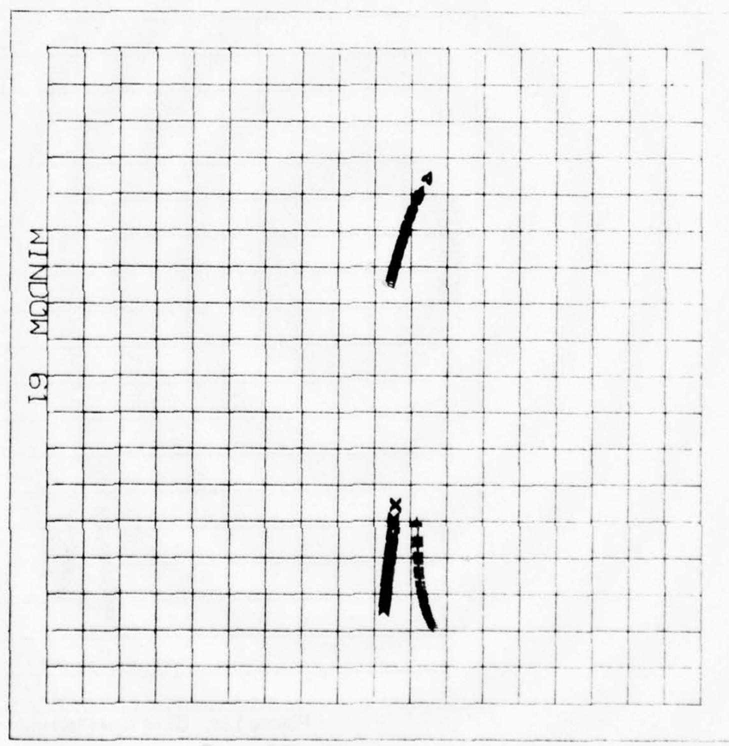
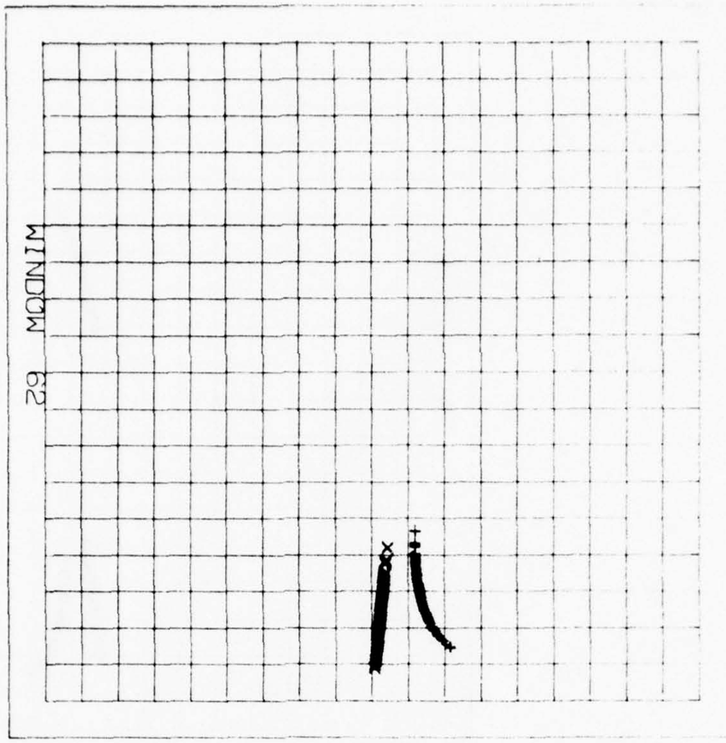


Figure 15b. Glint from right side windows.



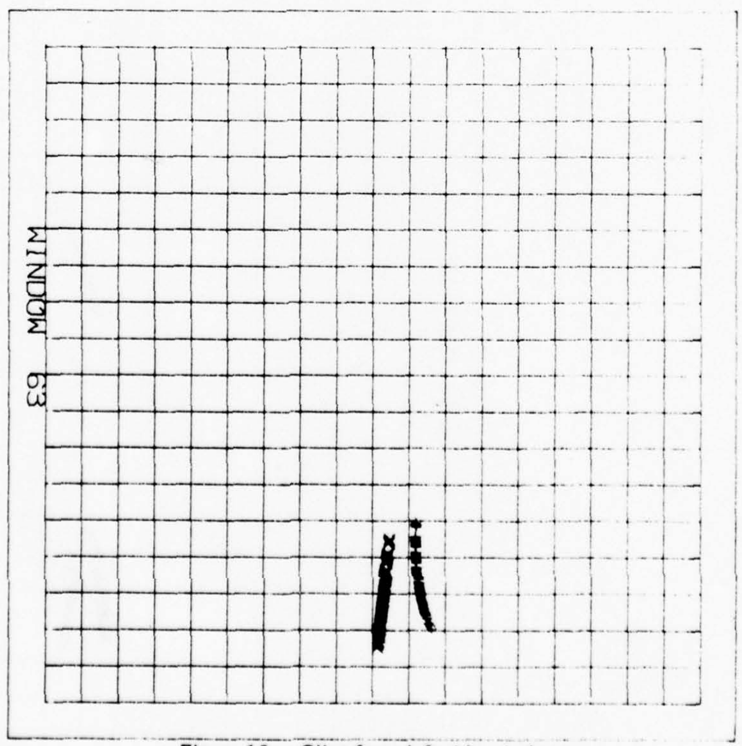


Figure 15c. Glint from left side windows.

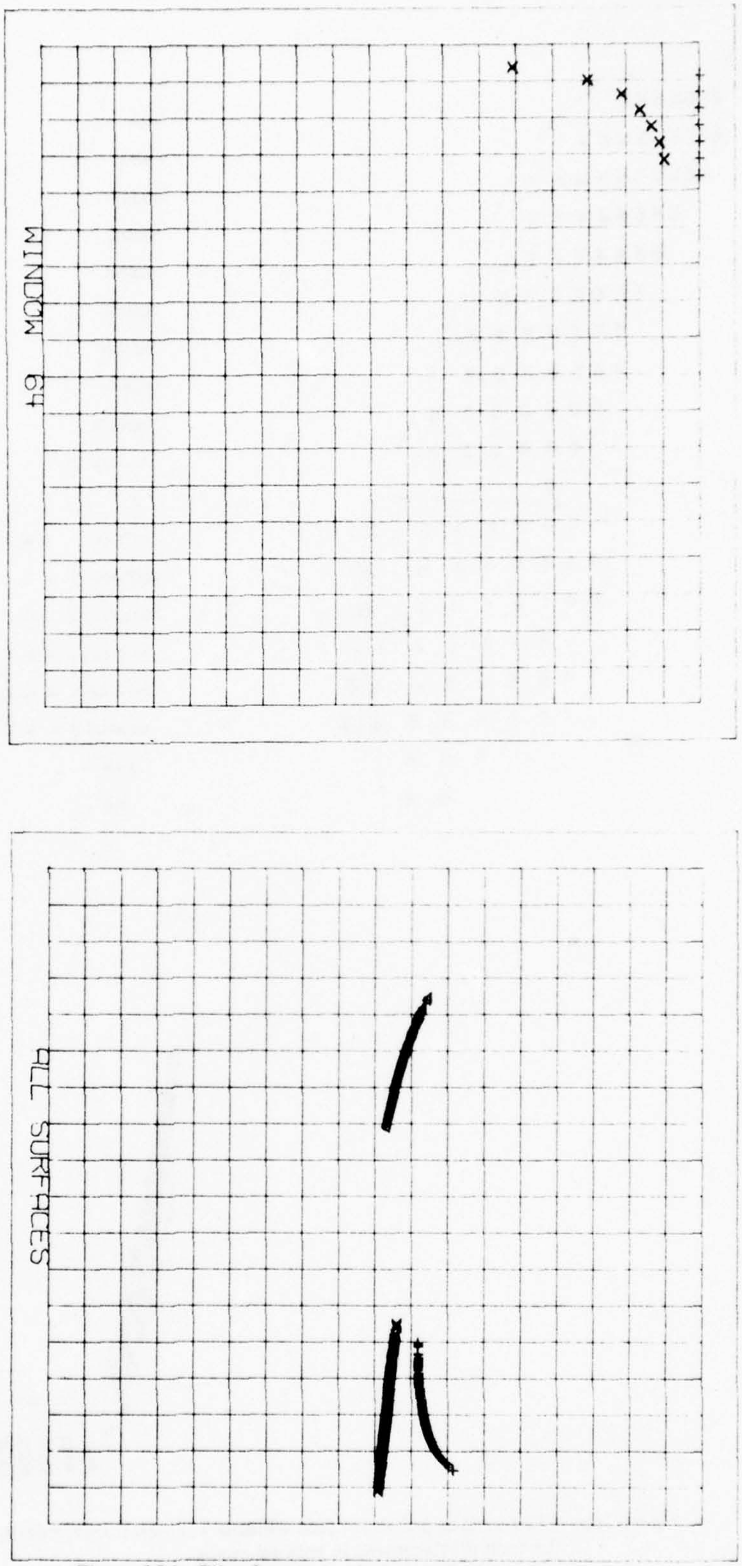


Figure 15d. Glint from top window and all windows combined.

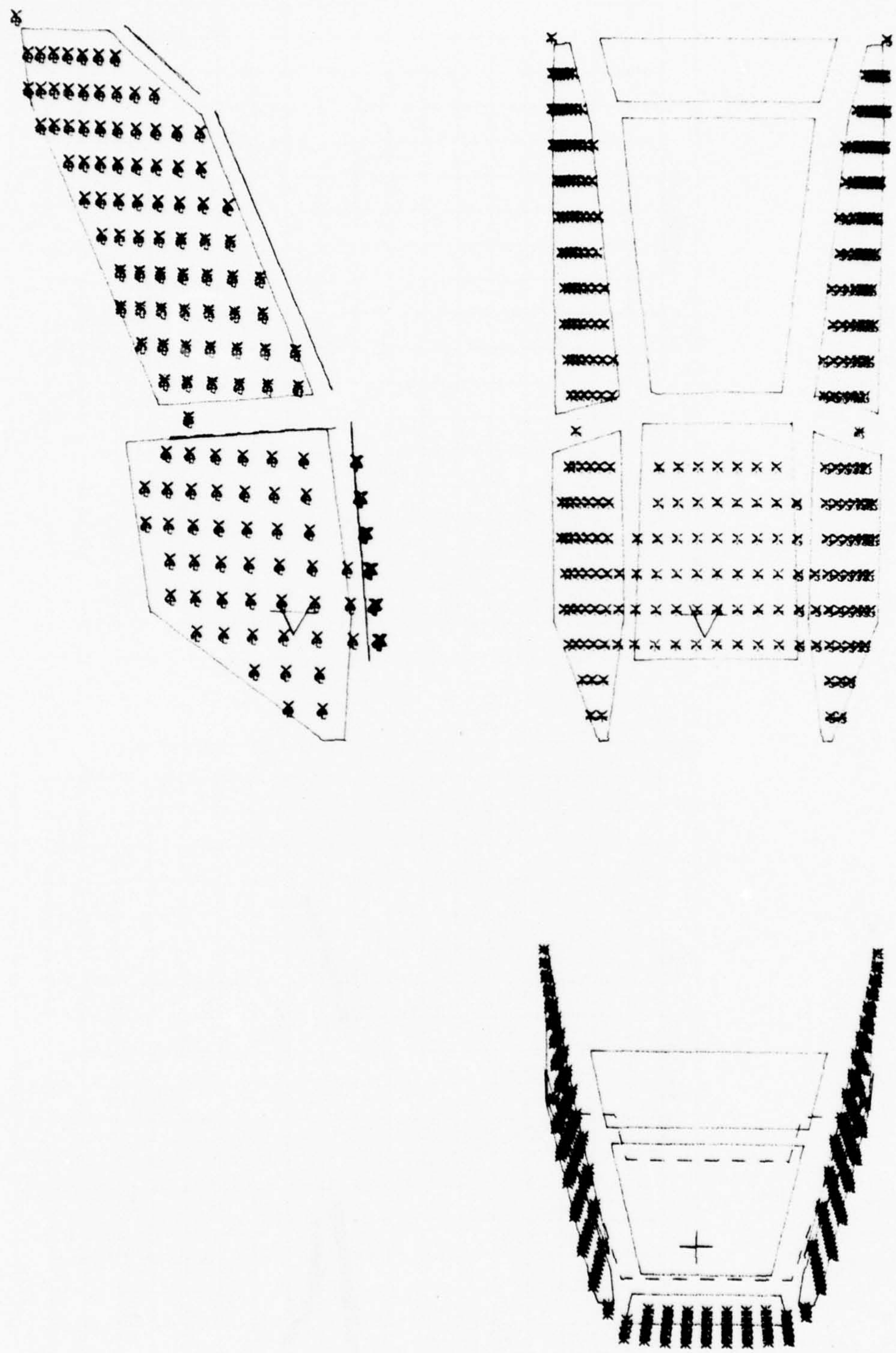


Figure 16a. Glint surface points for side window 1.0 inch displacement, top window 0.5 inch displacement in rotated mode.

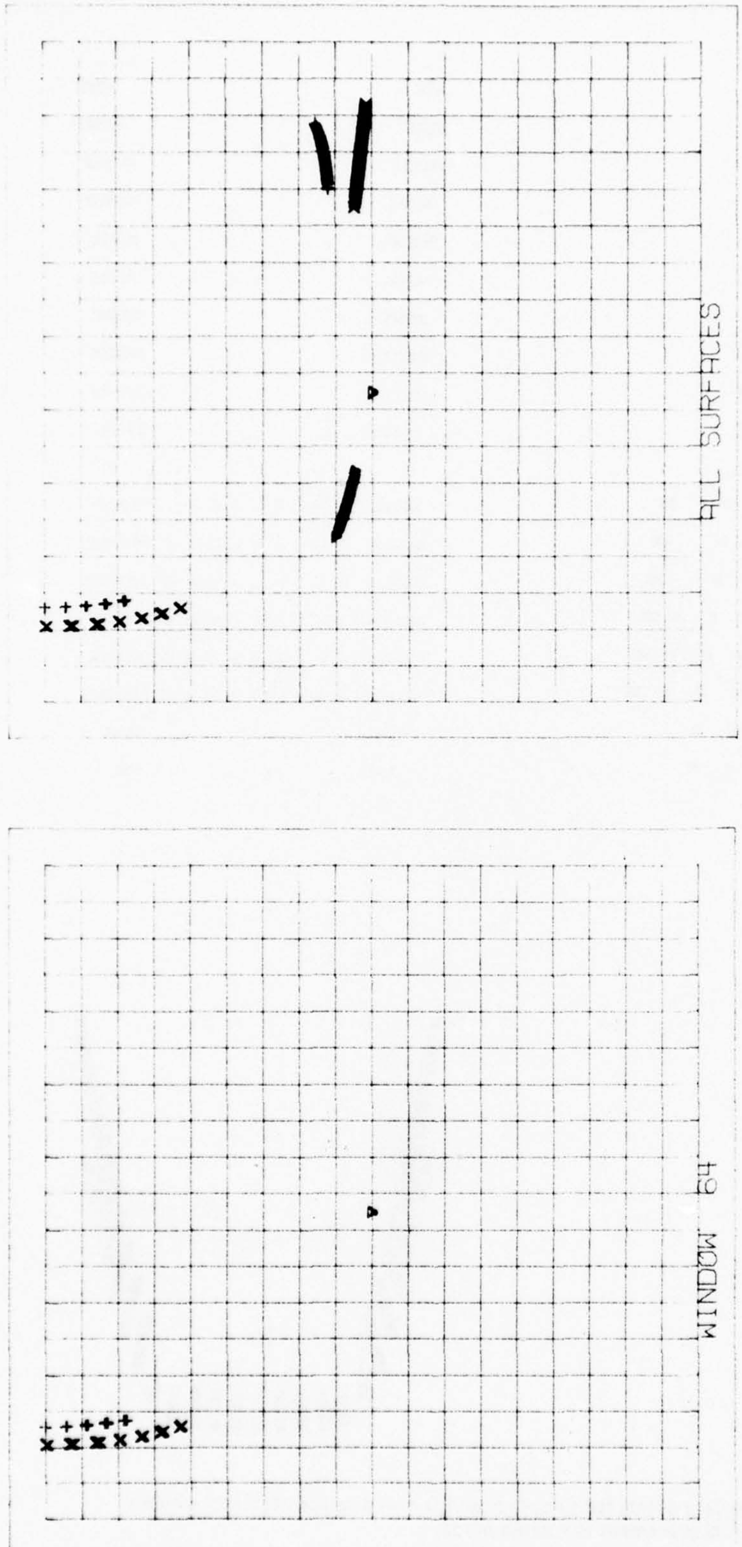


Figure 16b. Glint from top window and all windows combined.

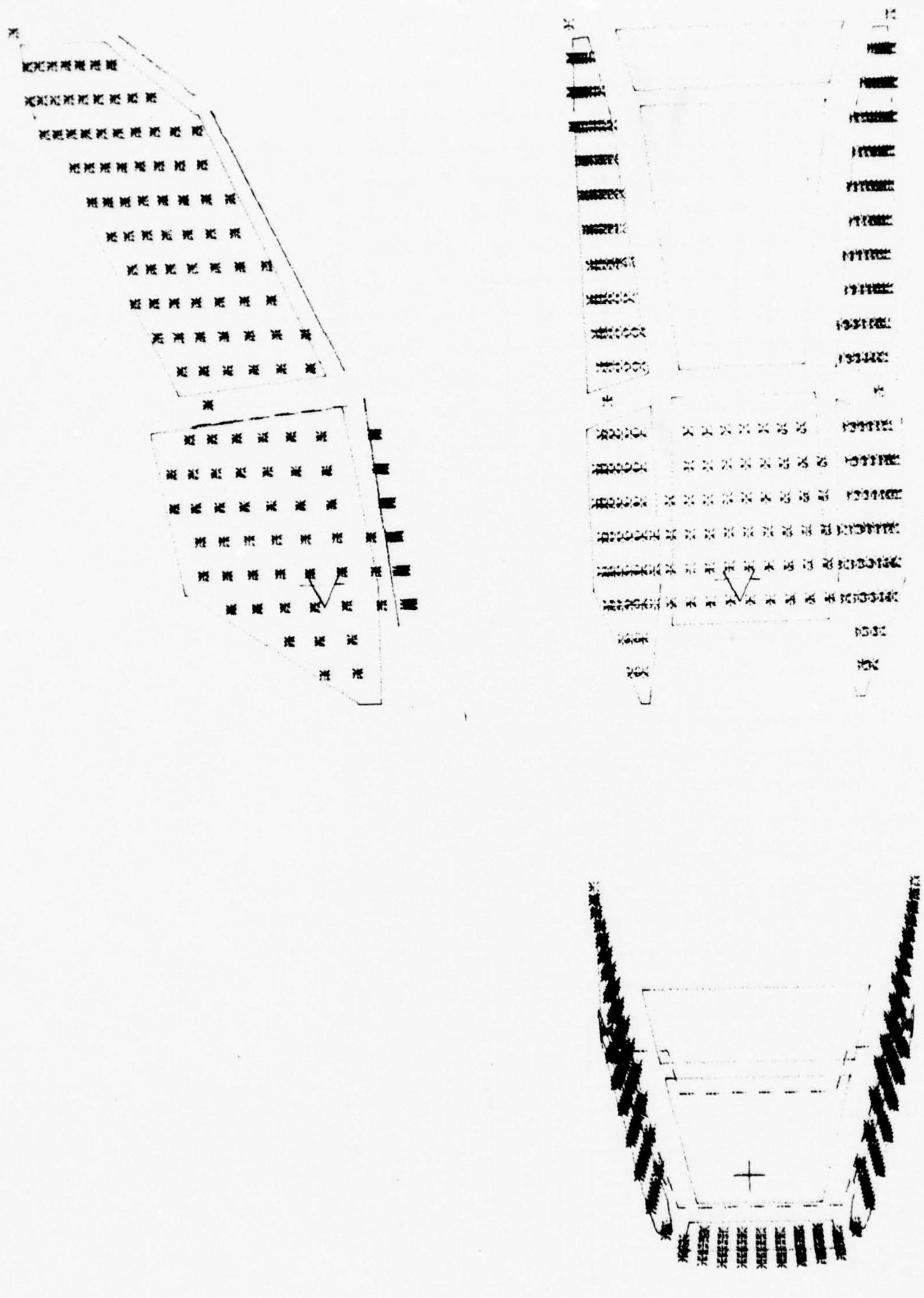


Figure 17a. Glint surface points for side window 1.0 inch displacement, top window 1.0 inch displacement in rotated mode.

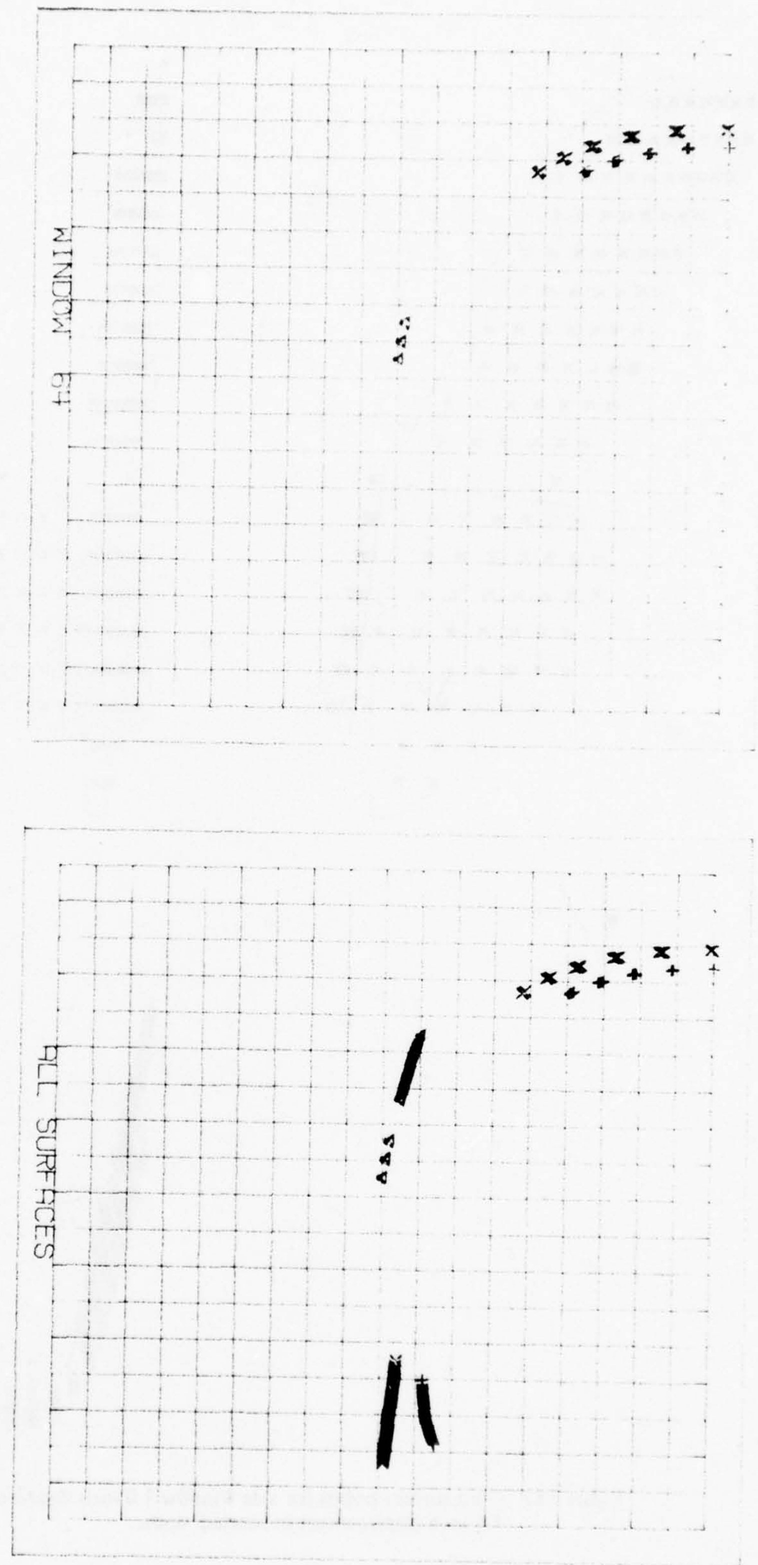


Figure 17b. Glint from top window and all windows combined.

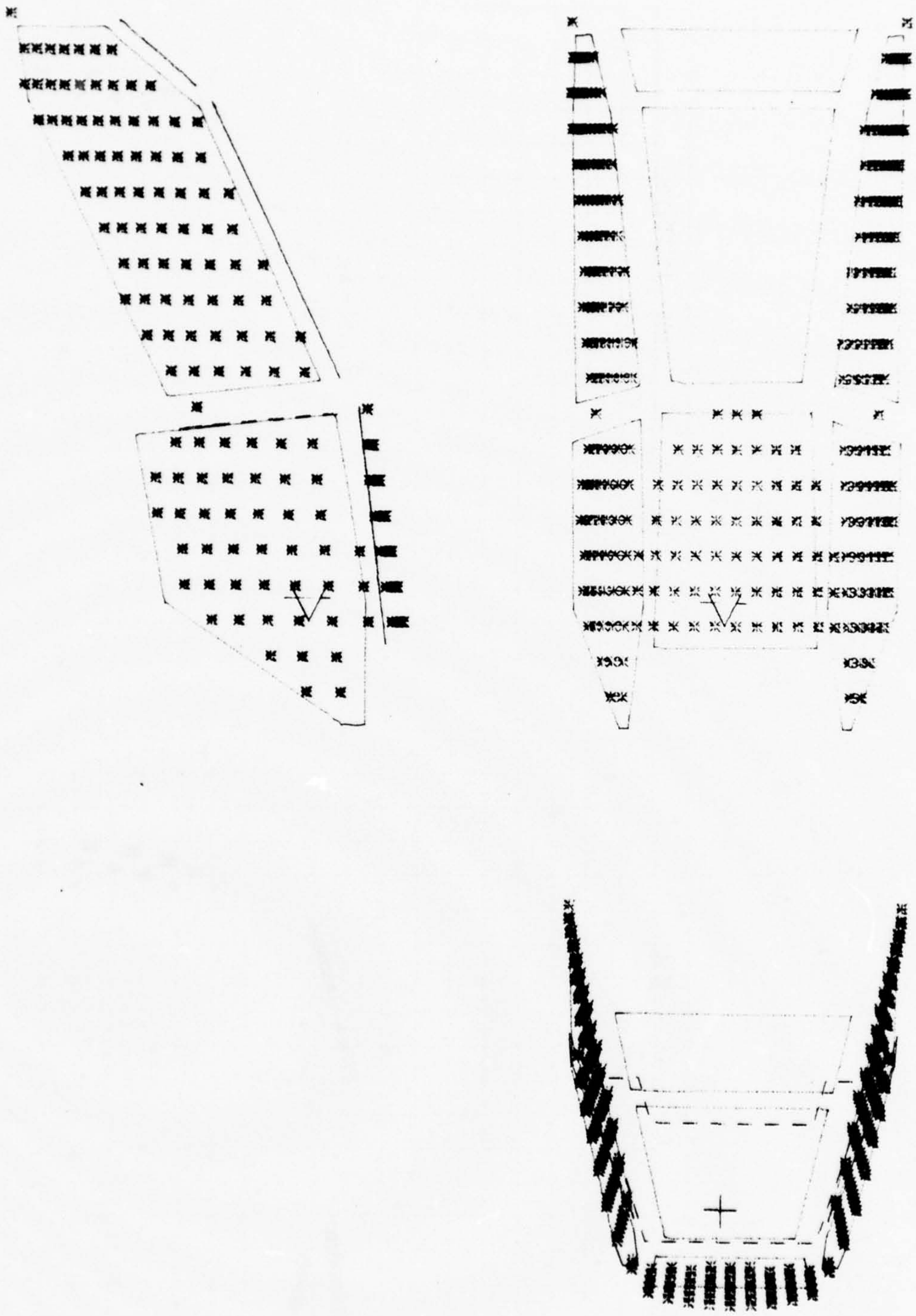


Figure 18a. Glint surface points for side window 1.0 inch displacement, top window 1.5 inch displacement in rotated mode.

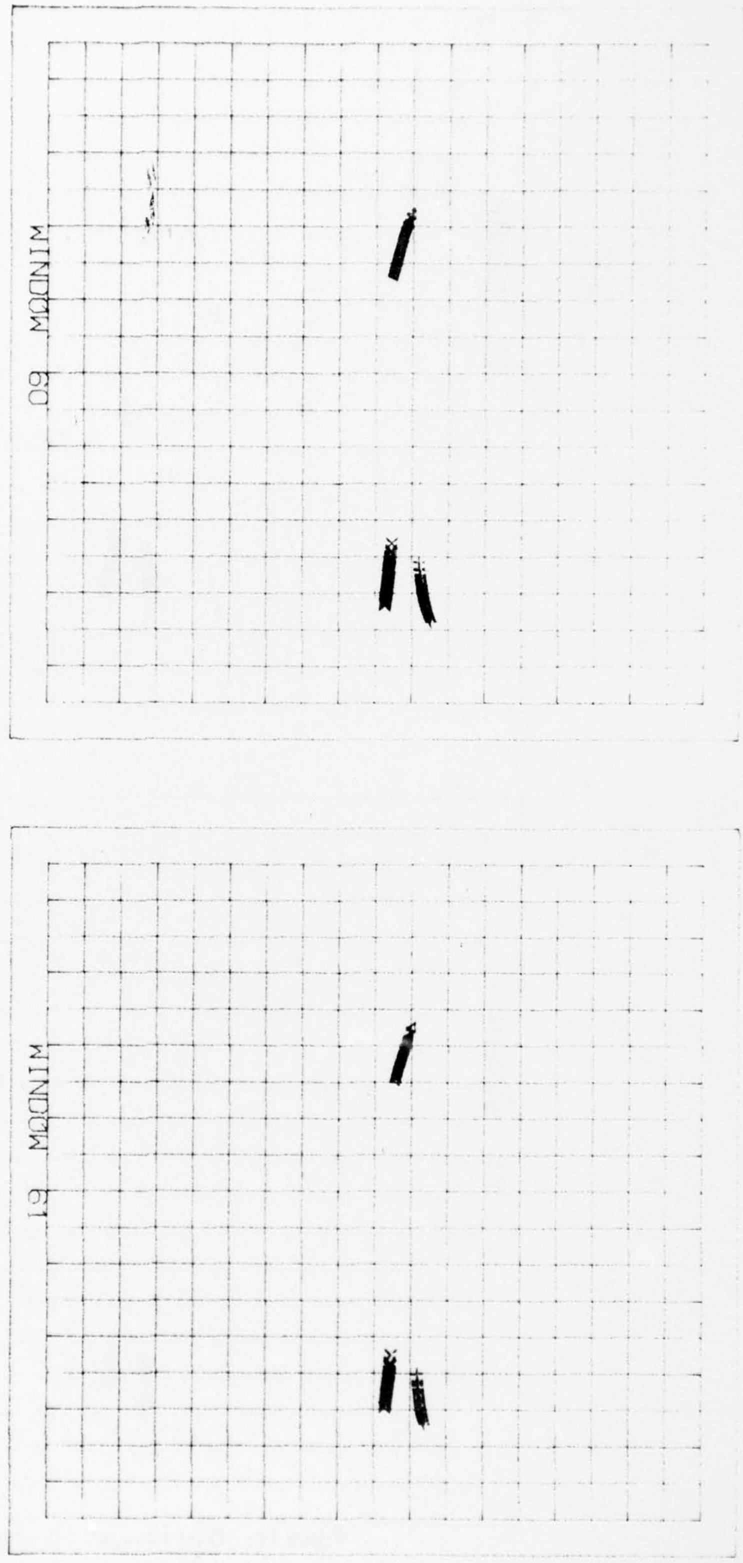
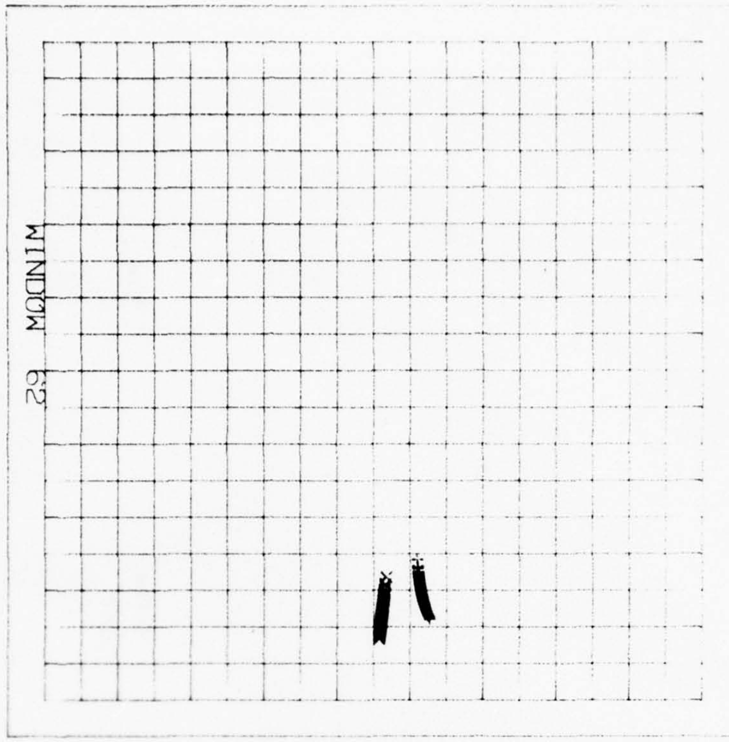


Figure 18b. Glint from right side windows.



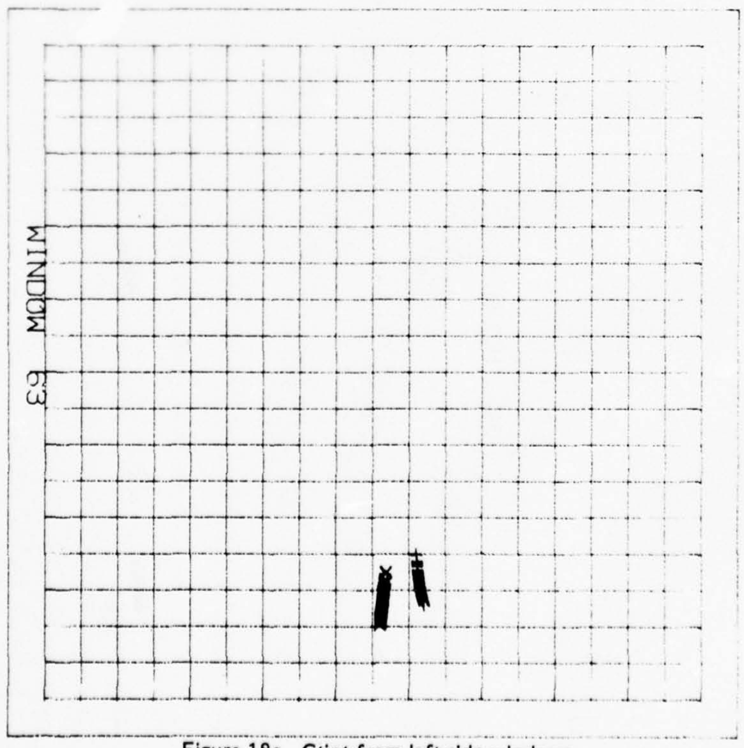
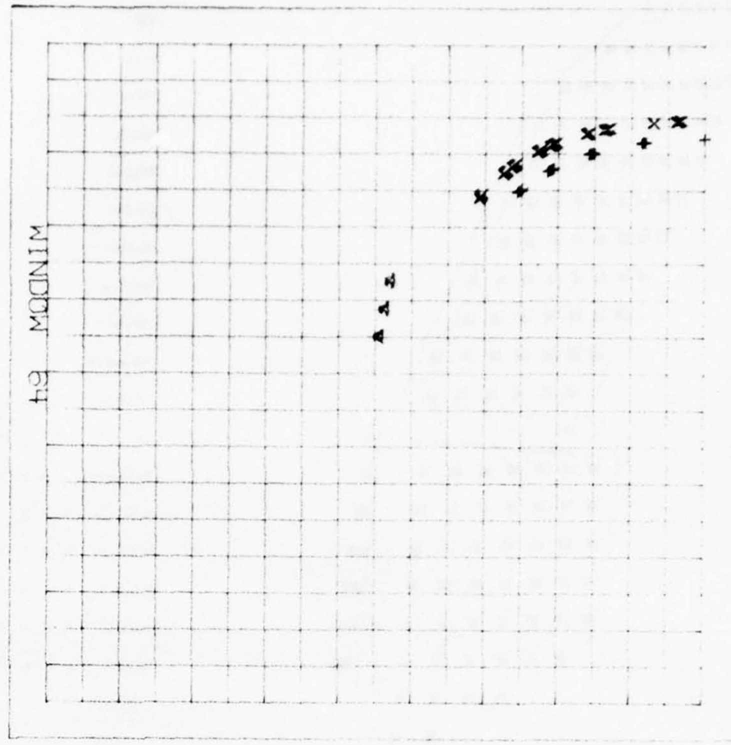


Figure 18c. Glint from left side windows.



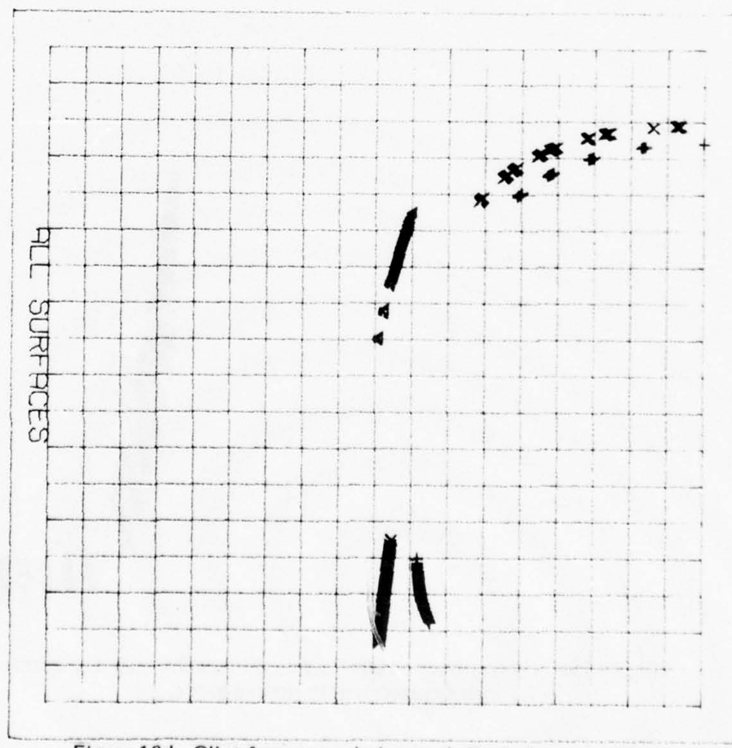


Figure 18d. Glint from top window and all windows combined.

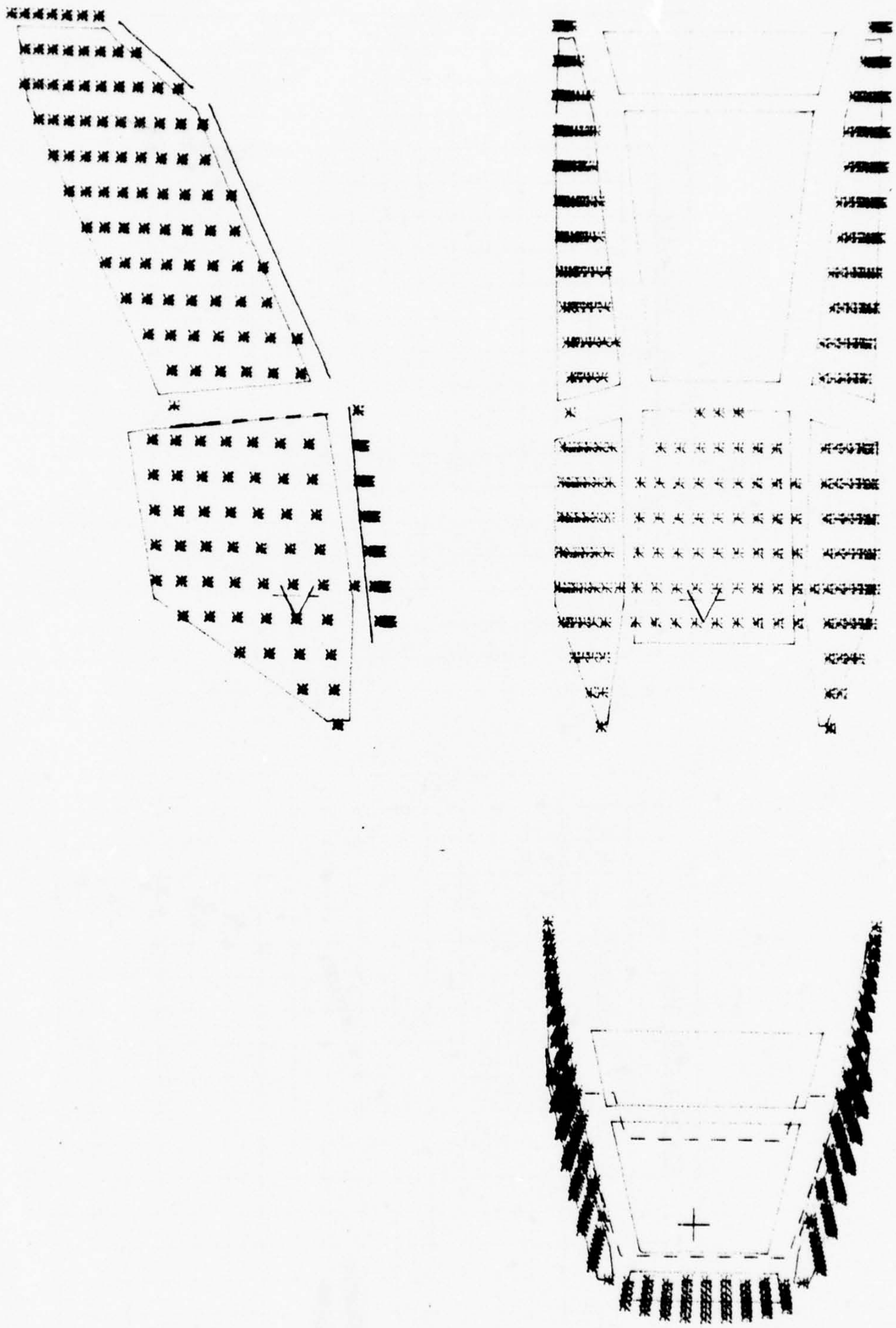
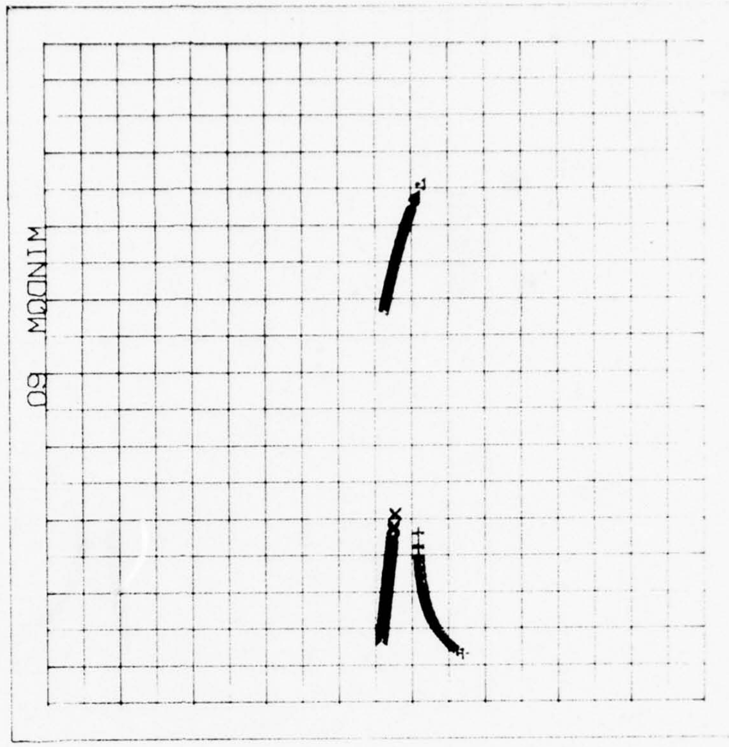


Figure 19a. Glint surface points for side window 2.0 inch displacement, top window 1.5 inch displacement in rotated mode.



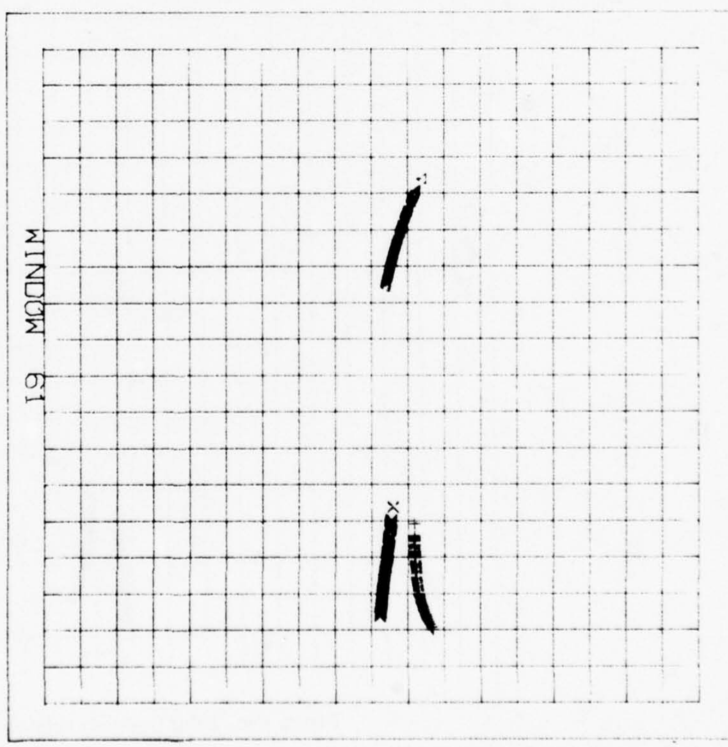
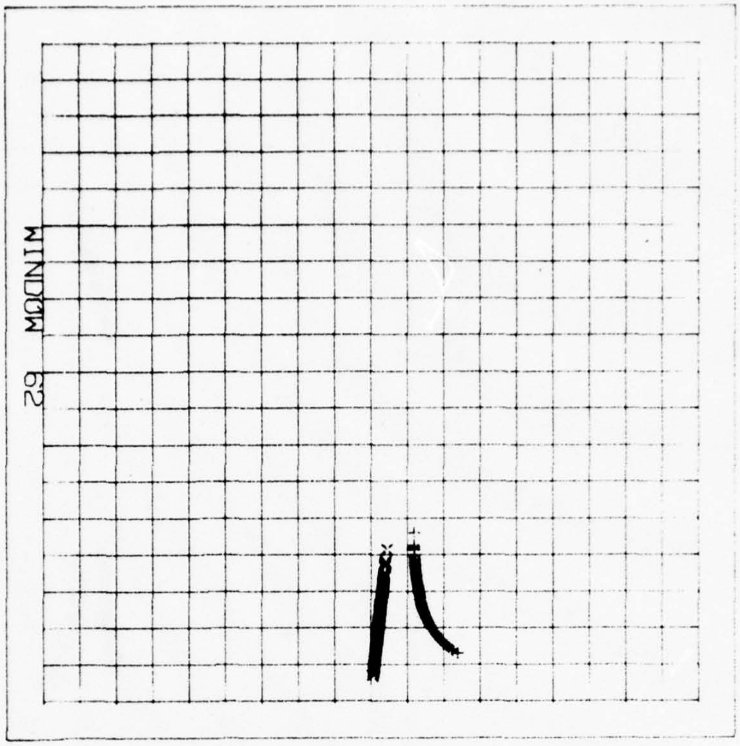


Figure 19b. Glint from right side windows.



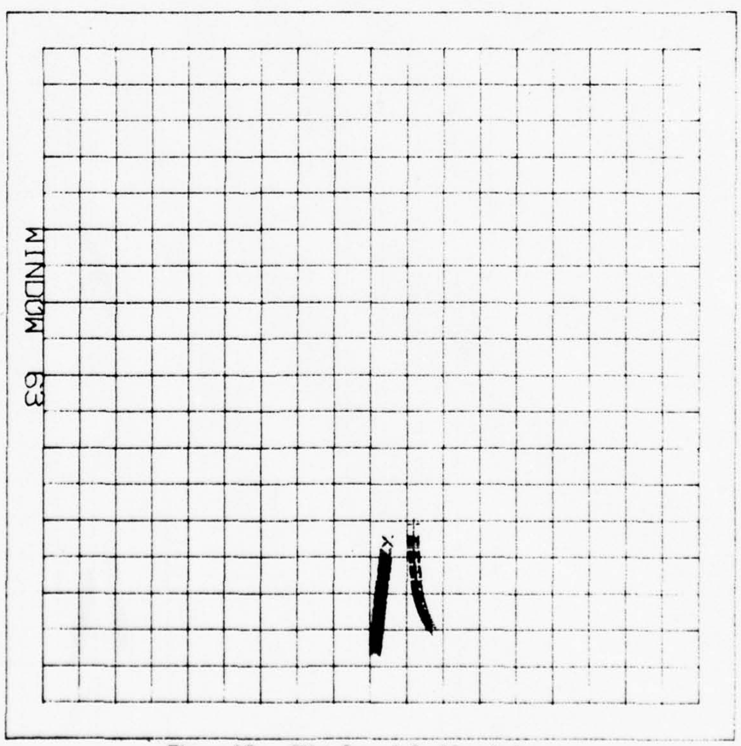


Figure 19c. Glint from left side windows.

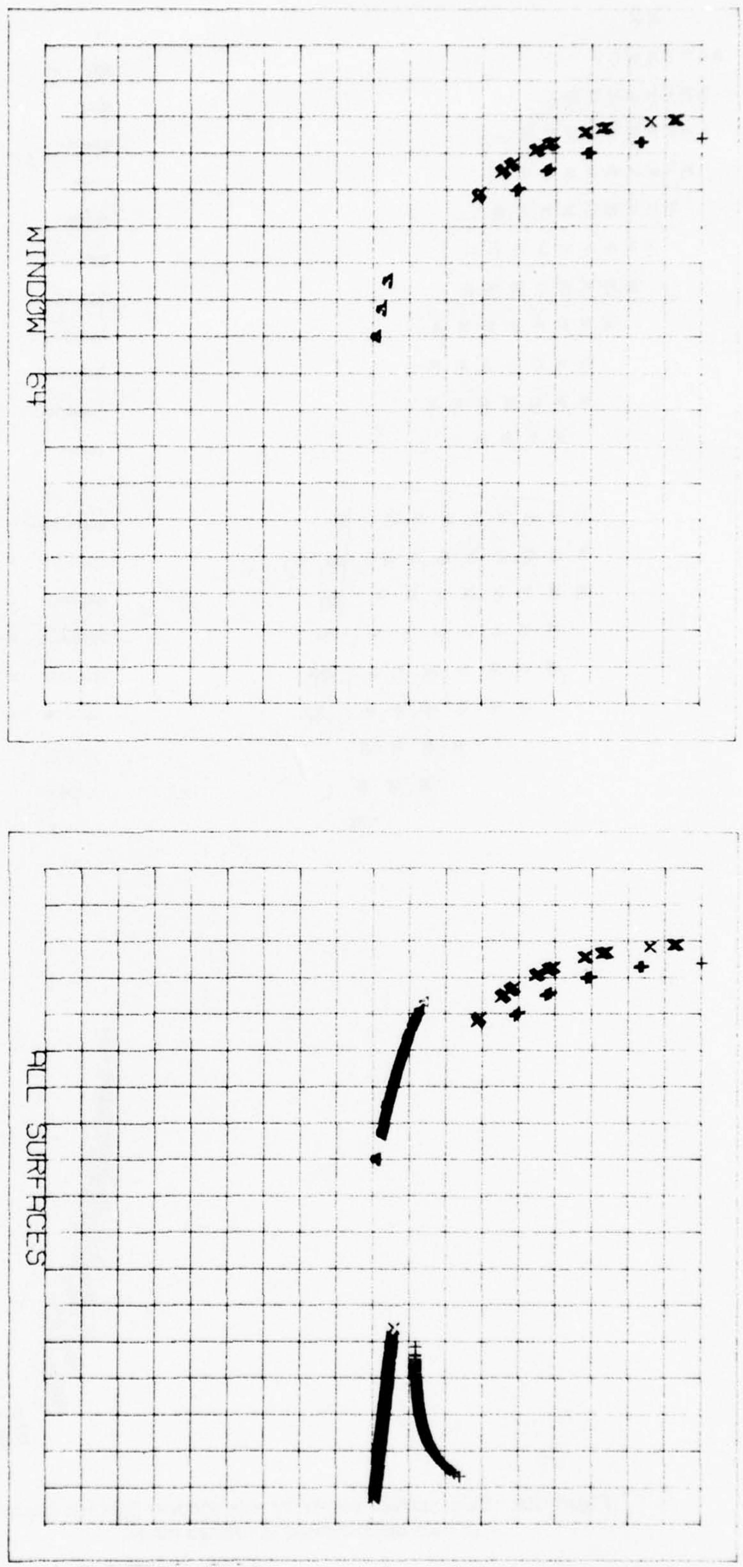


Figure 19d. Glint from top window and all windows combined.

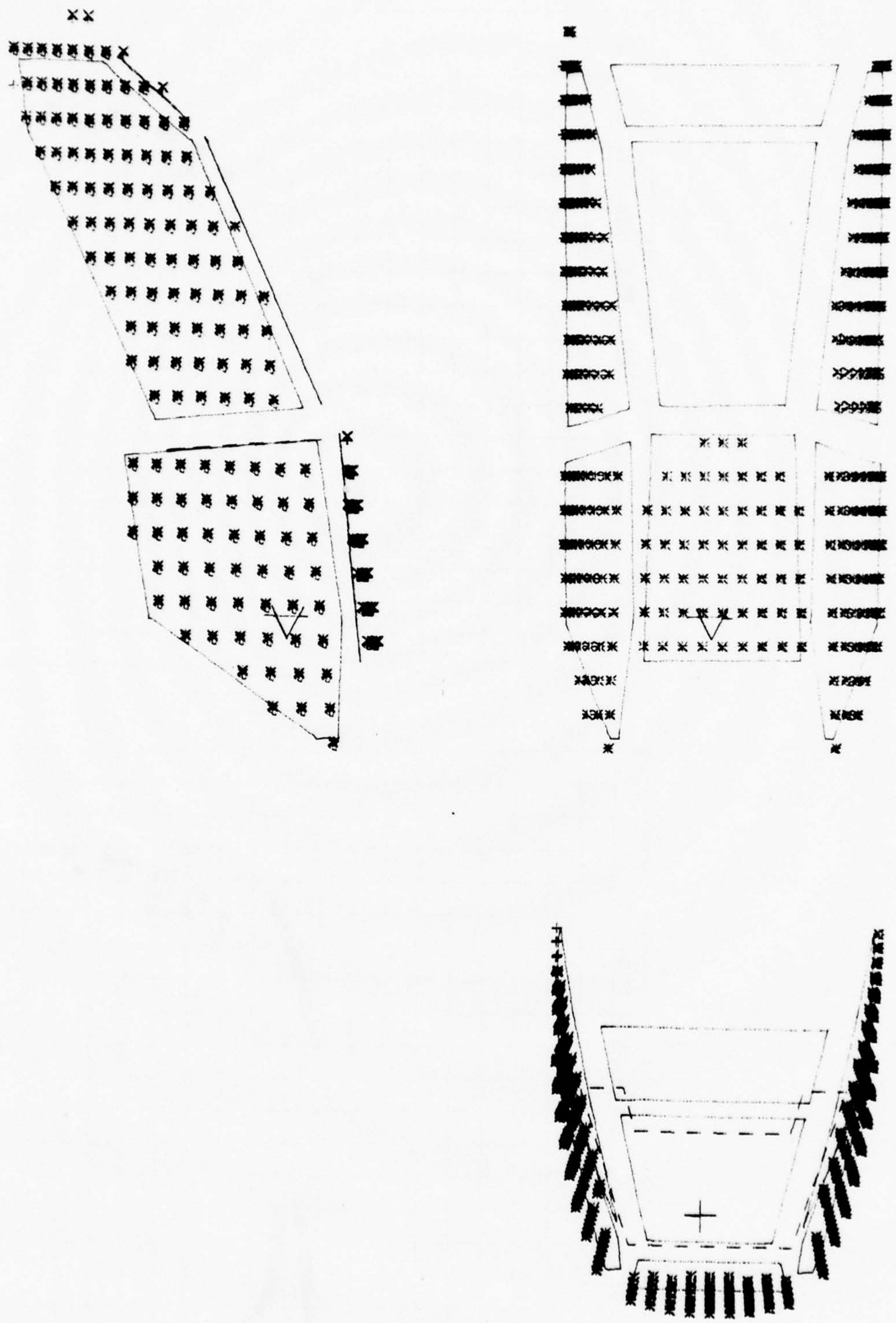
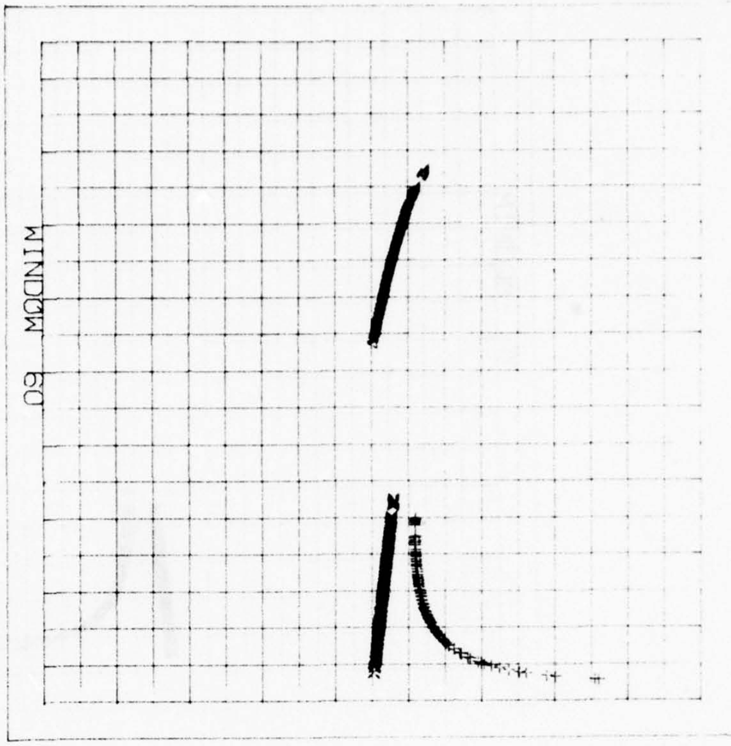


Figure 20a. Glint surface points for side window 3.0 inch displacement, top window 1.5 inch displacement in rotated mode.



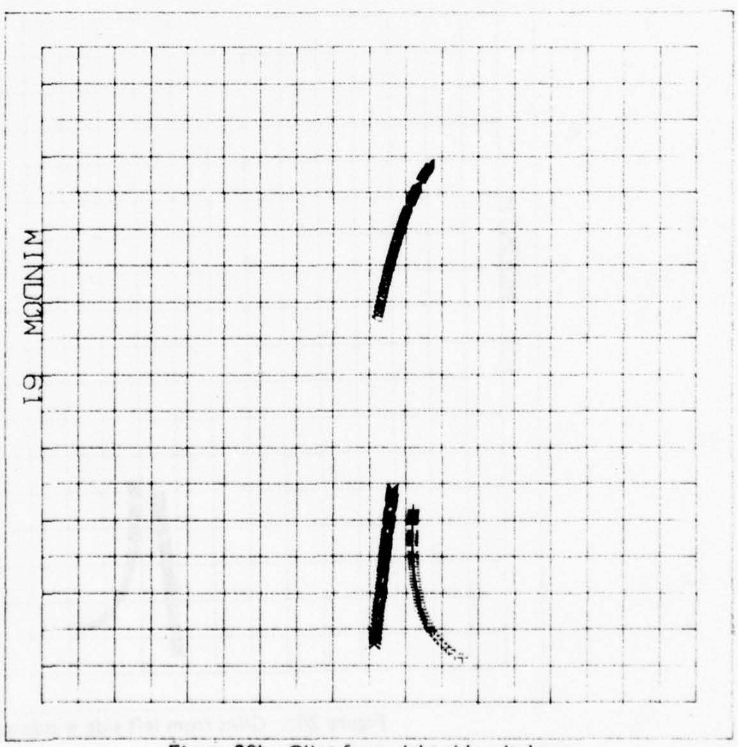


Figure 20b. Glint from right side windows.

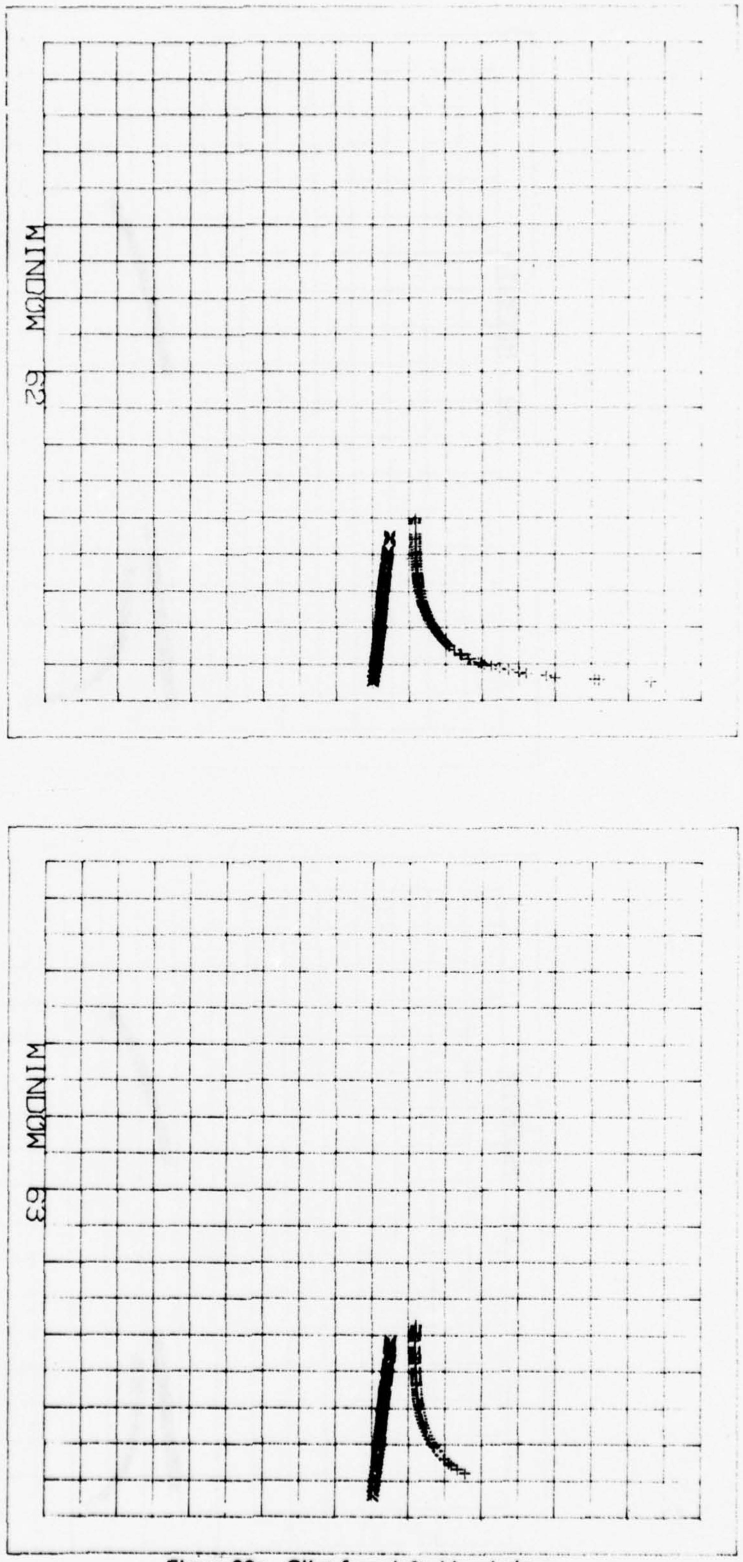


Figure 20c. Glint from left side windows.

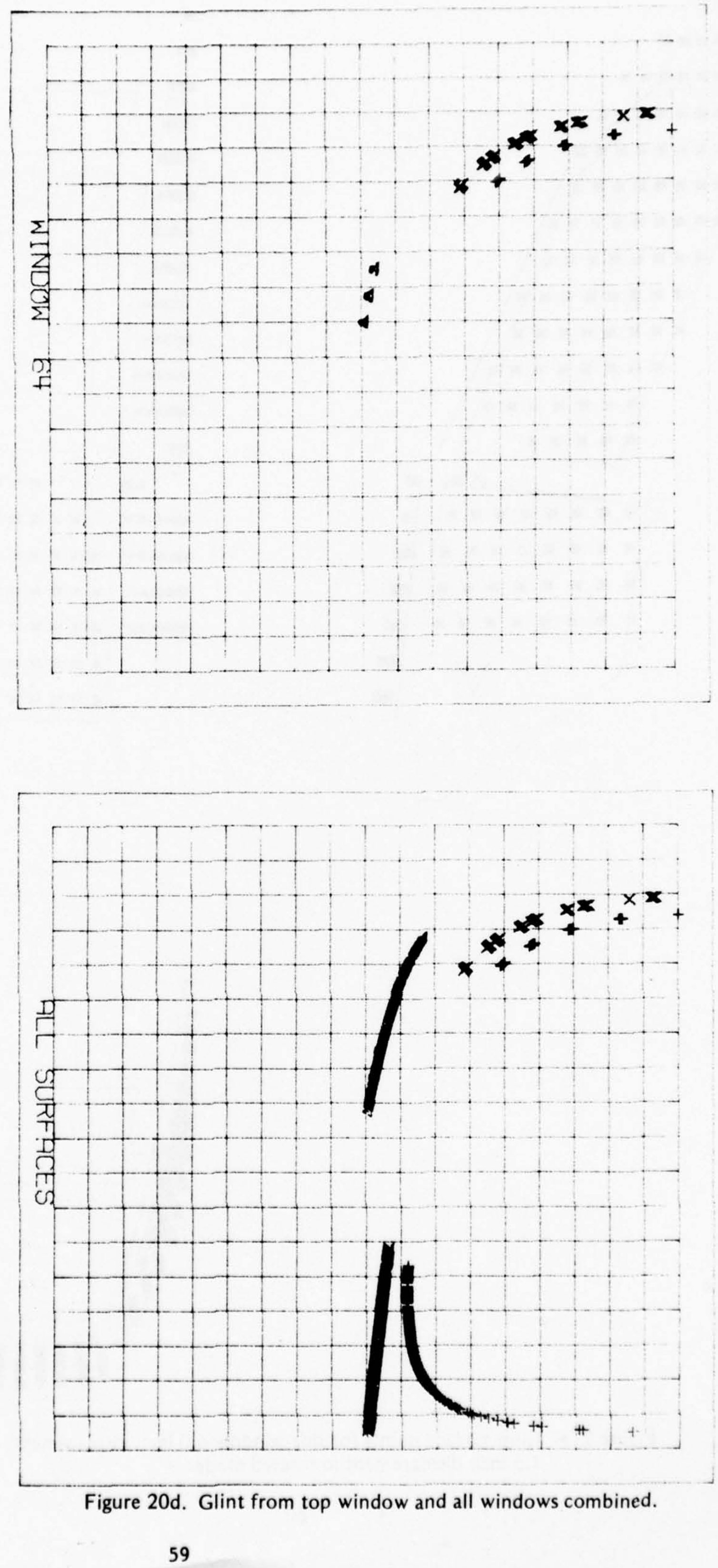


Figure 20d. Glint from top window and all windows combined.

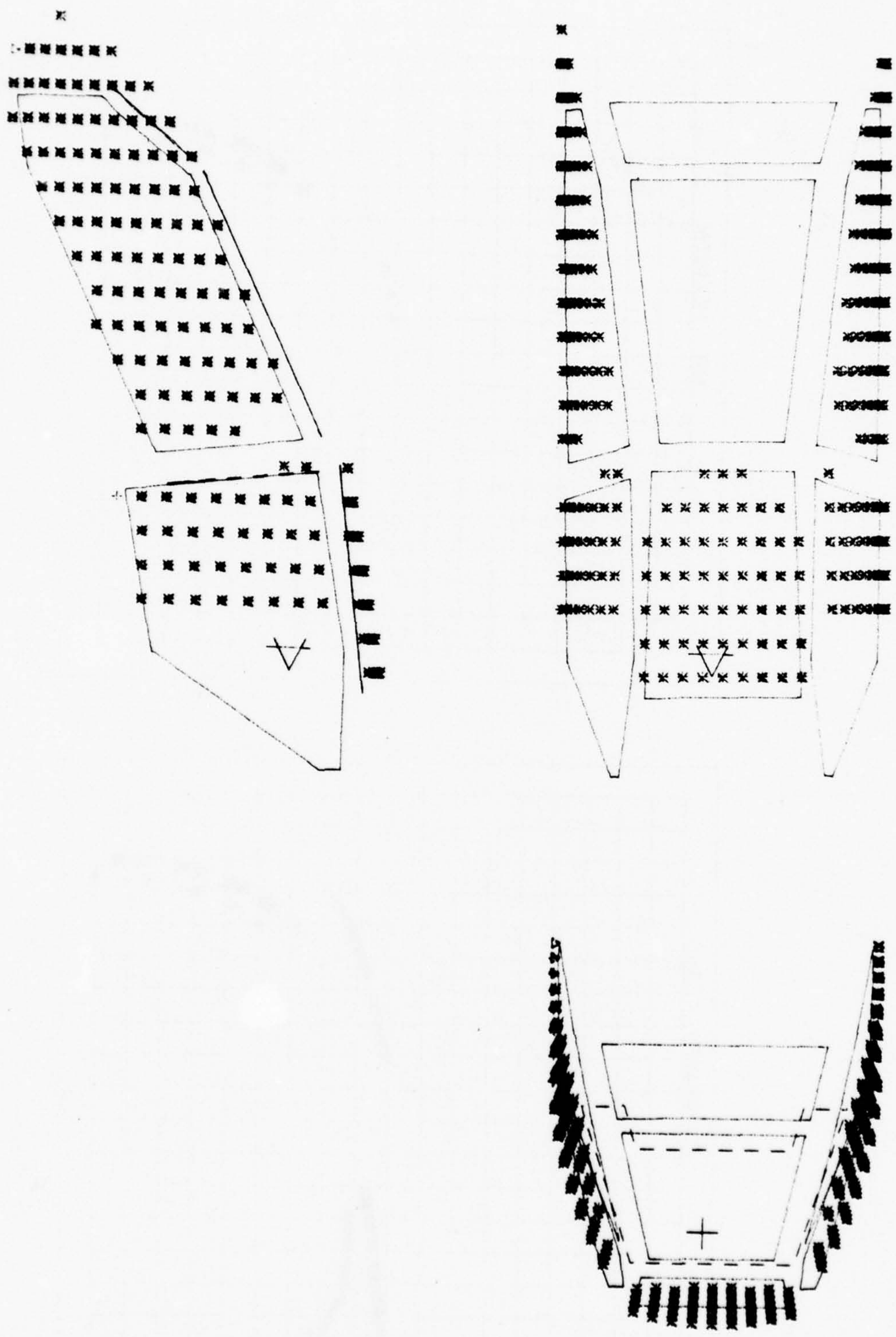


Figure 21a. Glint surface points for side window 4.0 inch displacement, top window 1.5 inch displacement in rotated mode.

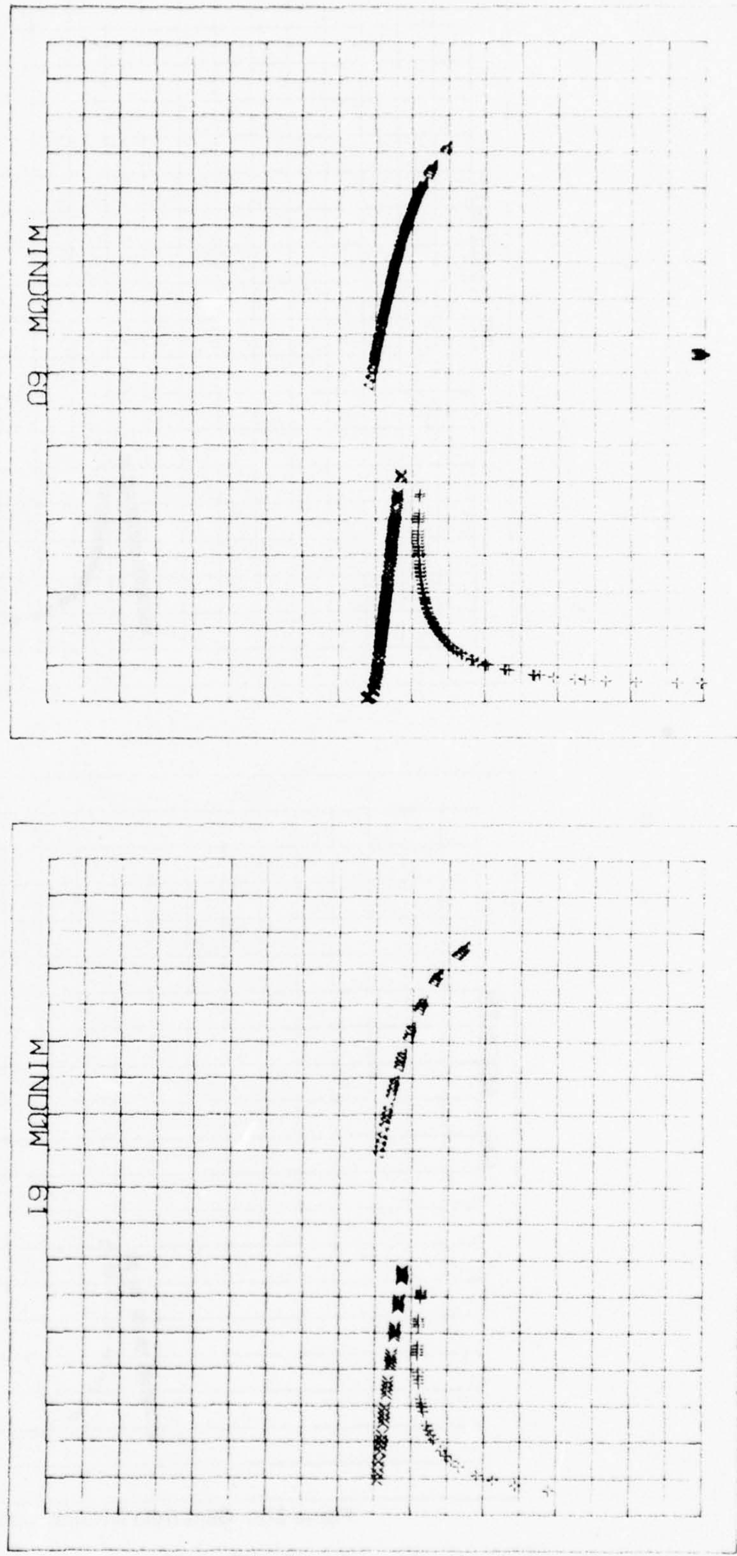
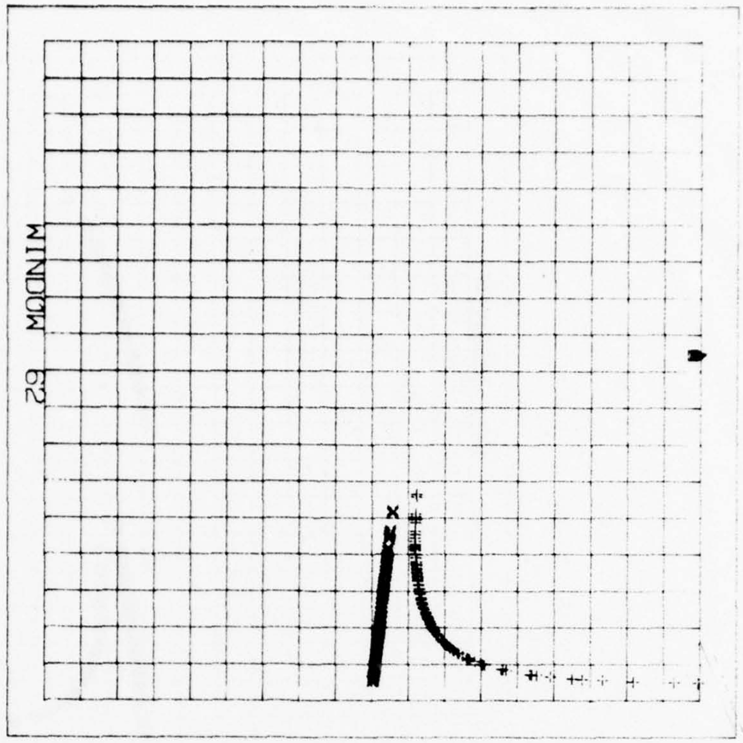


Figure 21b. Glint from right side windows.



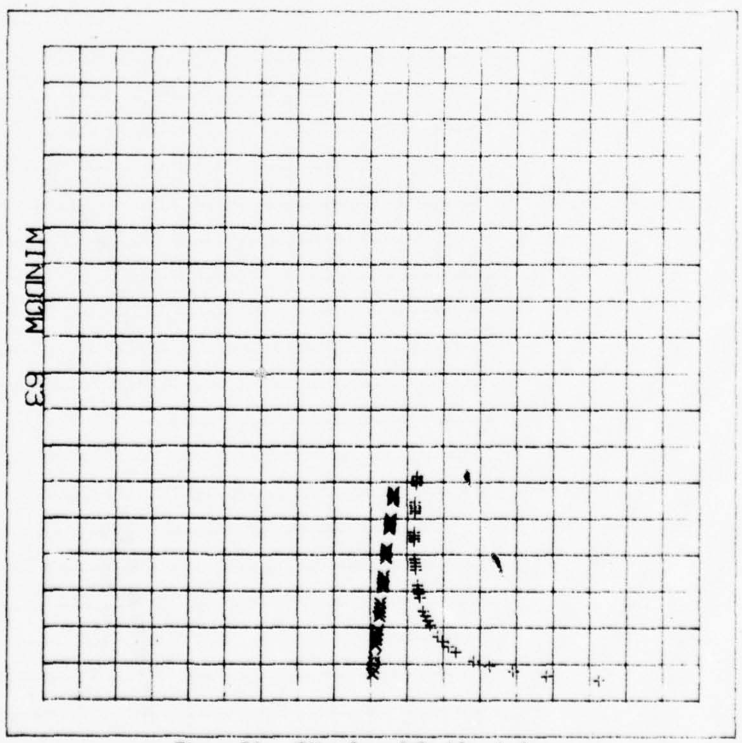
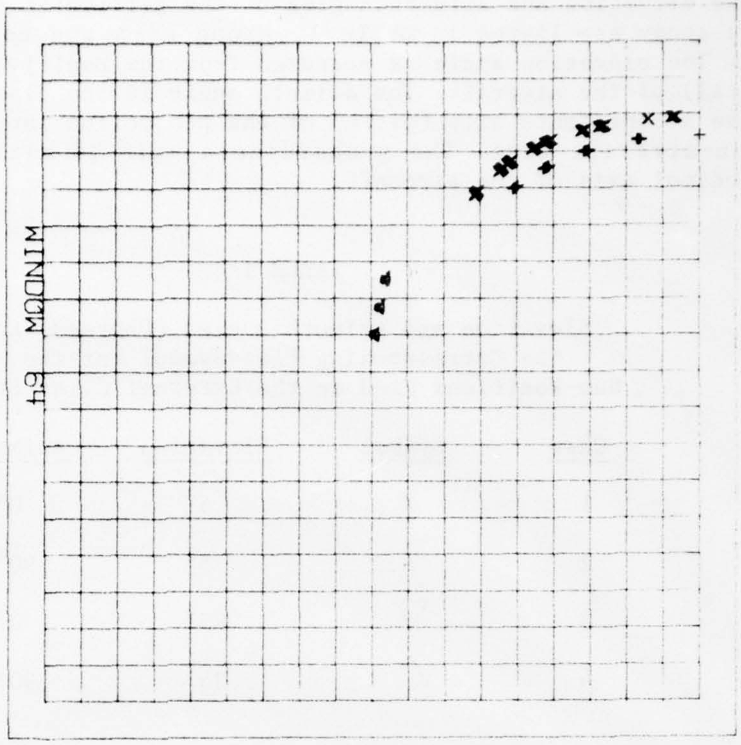


Figure 21c. Glint from left side windows.



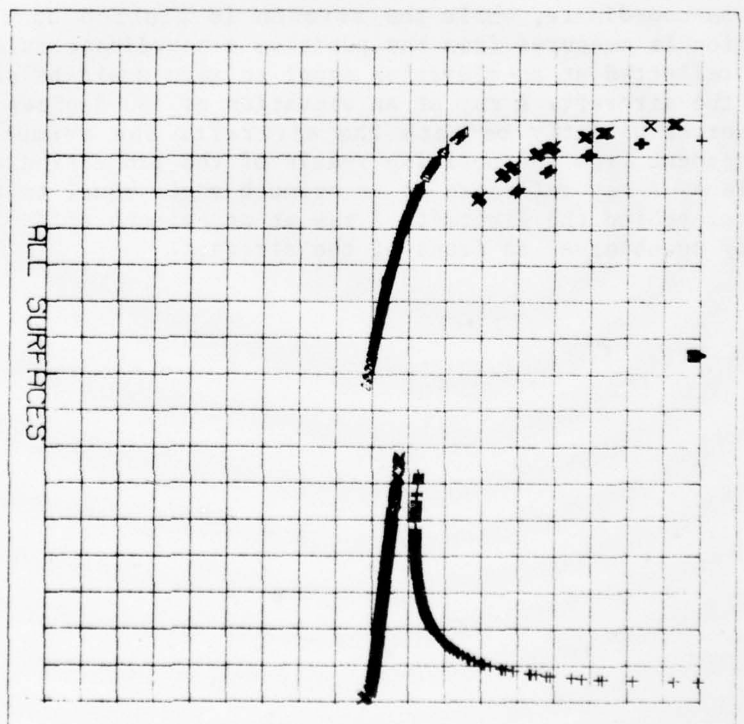


Figure 21d. Glint from top window and all windows combined.

The elevation and azimuth angles of the particular sun positions used in this study are listed in Table 1, along with the corresponding plot symbol. The elevation angle is measured from the positive z-coordinate axis (vertical) of the aircraft. The azimuth angle is the displacement from the positive x-coordinate axis (pitch) of the projection into the x-y plane of the sun-aircraft line. The y-coordinate axis is directed along the longitudinal axis of the aircraft.

TABLE 1

Elevation and Azimuth Angles (Degrees) and the Corresponding Plot Symbol for the Sun-Positions Used in the External Glint Study

Case	Symbol	Elevation	Azimuth
1	X	5°	0°
2	+	5°	90°
3	▽	95°	0°
4	△	95°	90°

The directions of the reflected rays are given on the plots by their elevation and azimuth angles. The elevation is plotted on the abscissa-coordinate, while the azimuth is plotted on the ordinate. The elevation is measured from the positive z-coordinate axis of the aircraft. A ray reflected at an elevation equal to zero would be seen by an observer above the aircraft. A ray at an elevation of 180 degrees would be seen by an observer directly beneath the aircraft. The azimuth is the angular displacement from the positive y-axis of the projection of the ray onto the x-y plane. A ray reflected at an azimuth angle equal to zero is seen by an observer behind the aircraft. A ray at an azimuth of 180 degrees would be seen by an observer in front of the aircraft.

Figures 15a through 15d show the external glint which is generated by the present LGC design at the sun positions used in this study. Figure 15a shows the surface points used to compute the external glint on side, top, and front views of the canopy frame. Figures 15b and 15c show the angular directions of the reflected glint for the right and left side windows, while Figure 15d shows the glint for the top window and all windows combined.

Figures 16 through 18 show similar plots for the aircraft with the top window in the rotated configuration. The figures show the glint results for the top window displaced 0.5, 1.0, and 1.5 inches from the vertice plane, and the side window held fixed at a 1.0-inch displacement. Figures 18 through 21 show plots for side window displacements of 1.0, 2.0, 3.0, and 4.0 inches from the vertice plane, and the top window held fixed at a 1.5-inches displacement.

The figures show a progressive increase in the angles at which the glint from the aircraft is visible, as the displacements of the side and top windows are increased. However, the locus of the glint angles is a line for all sun positions, and the glint is not visible over a solid angle. The line locus for the glint angles results from the choice of cylindrical segments for the LGC design side and top windows. The locus of the glint angles for the remaining flat windows are single points for any one sun-position.

Optical Distortions

The results of the computations for the optical distortions and transmittance are shown in Figures 22 and 23. The figures show point-wise measures of the optical distortions and transmittances spaced at equal intervals on side, top and front views of the aircraft canopy frame. The figures for a particular choice of side and top window displacements, are presented in paired sets with the first figure showing the optical distortion and the second figure showing the transmittance values. Figure 22 shows the results for the present LGC design, while Figure 23 shows that for the design with a 4-inch side window displacement and a 1.5-inch top window displacement in the rotated mode.

A comparison of Figures 22 and 23 shows how the two designs differ in optical distortions and transmittance. The modified design of Figure 23 shows an increase in optical distortion and a decrease in transmittance over that portion of the top window which is directly over the pilot. However, the optical distortions and transmittances are not changed over the remainder of the window surfaces from that for the present LGC design. This is true to the degree of measure exhibited in the figures.

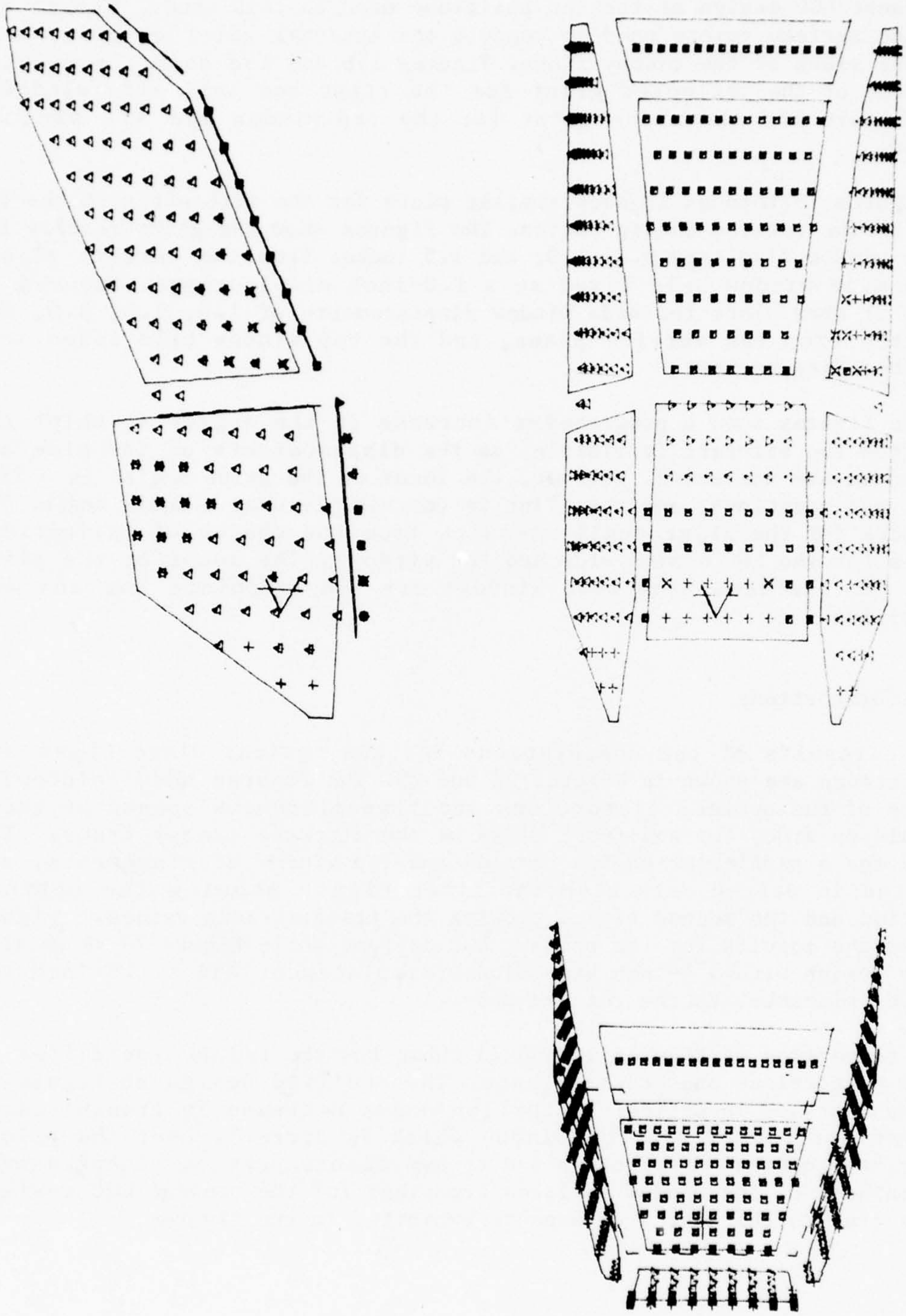


Figure 22a. Optical distortions on present design.

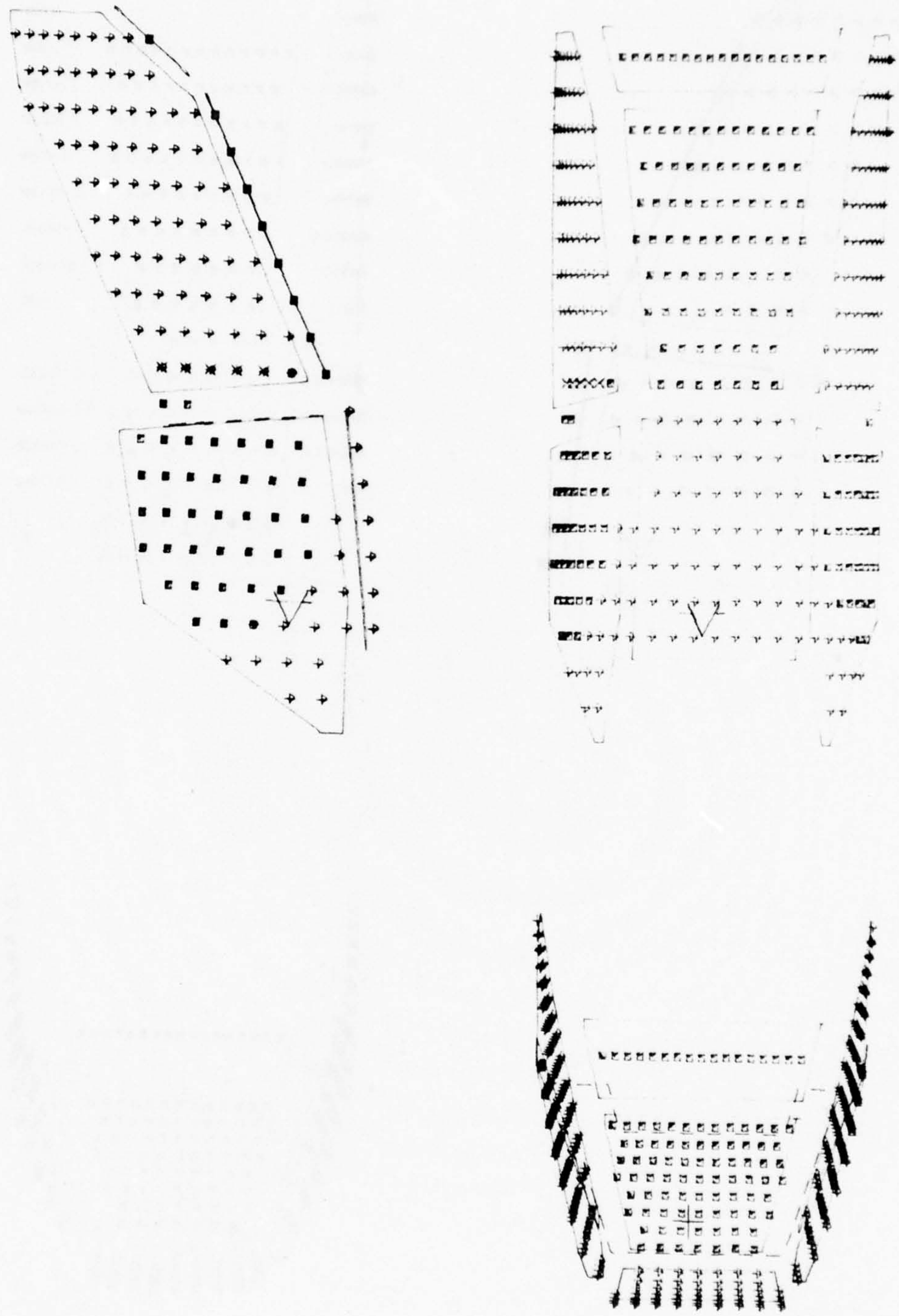


Figure 22b. Transmittance values in present design.

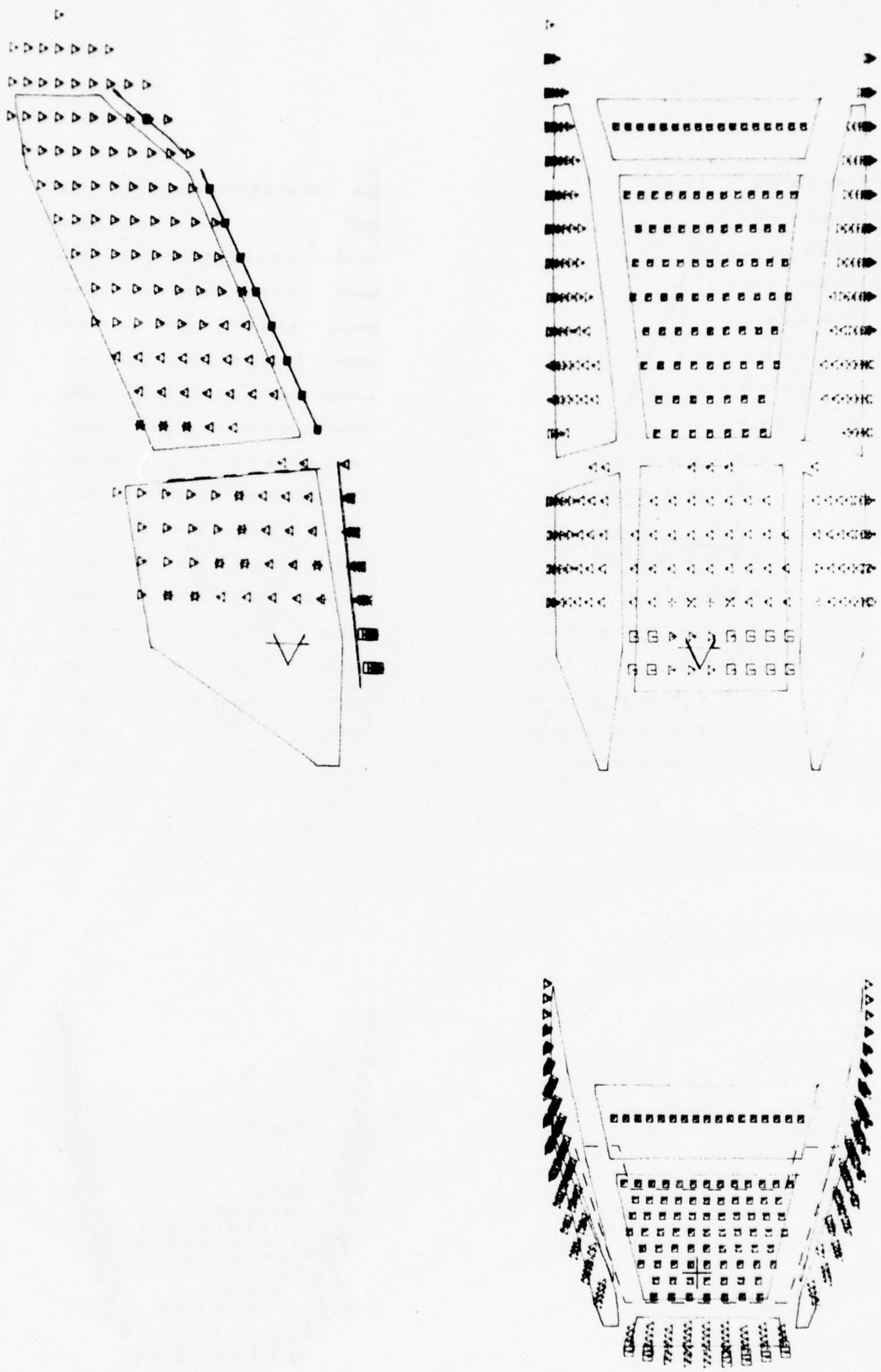


Figure 23a. Optical distortions for side displacements 4.0 inches and top displacement of 1.5 inches in rotated mode.

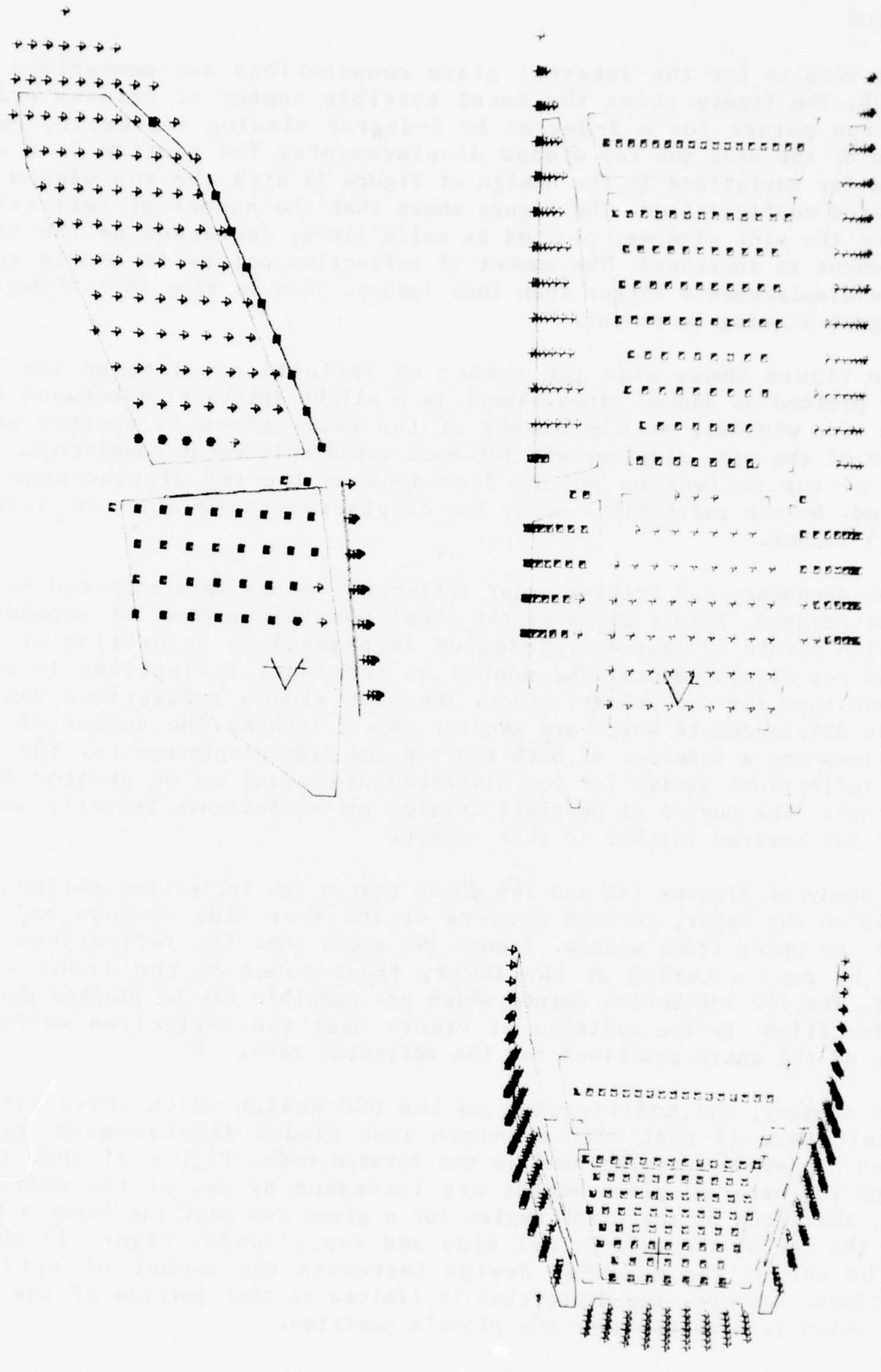


Figure 23b. Transmittance value for side displacements 4.0 inches and top displacement 1.5 inches in rotated mode.

DISCUSSION

The results for the internal glare computations are summarized in Figure 24. The figure shows the total possible number of primary order reflection points for a 2-degree by 2-degree viewing increment, as a function of the side and top window displacements. The plotted data was computed for variations in the design of Figure 14 with the top window in the rotated configuration. The figure shows that the number of reflection points on the side windows, plotted as solid lines, decreases as the side displacement is increased. The number of reflection points is nearly zero for side displacements larger than four inches. This is true for a 2-degree by 2-degree viewing increment.

The figure shows also the number of reflection points on the top window, plotted as dashed lines. There is a slight interaction between the top and side windows, and the number of top reflections is plotted as a function of the side displacement for each top displacement considered. The number of top reflection points decreases as the top displacement is increased. No top reflections occur for displacements equal to or larger than 1.5 inches.

The secondary and triplex order reflection points were computed using the same program. Figure 25 shows the total possible number of secondary reflection points (2-degree by 2-degree increment) as a function of the side and top displacements. The number of secondary reflections is much less than that for the primary order. The side window reflections vanish for side displacements which are greater than 2 inches. The number of top reflections are a function of both the top and side displacements. The top window reflections vanish for top displacements equal to or greater than 1.5 inches. The number of possible triplex reflections are trivally small and are not covered further in this report.

A study of Figures 14a and 14b shows that a few reflection points are possible on the upper, forward corners of the rear side windows and the edge of the upper front window. Figure 14b shows that the reflections are caused by rays entering at the lower, front cover of the front side windows. The few reflection points which are possible may be blocked during nighttime flight by the addition of visors over the reflection surfaces area or at the entry positions for the reflected rays.

In summary, one modification to the LGC design which shows little internal glare is that with a 4-inch side window displacement and a 1.5-inch top window displacement in the rotated mode. Figure 21 show that although the external glint angles are increased by use of the modified design, the locus of the glint angles for a given sun position forms a line due to the use of the cylindrical side and top windows. Figure 23 shows that the use of the modified design increases the amount of optical distortions. However, the distortion is limited to that portion of the top window which is directly over the pilot's position.

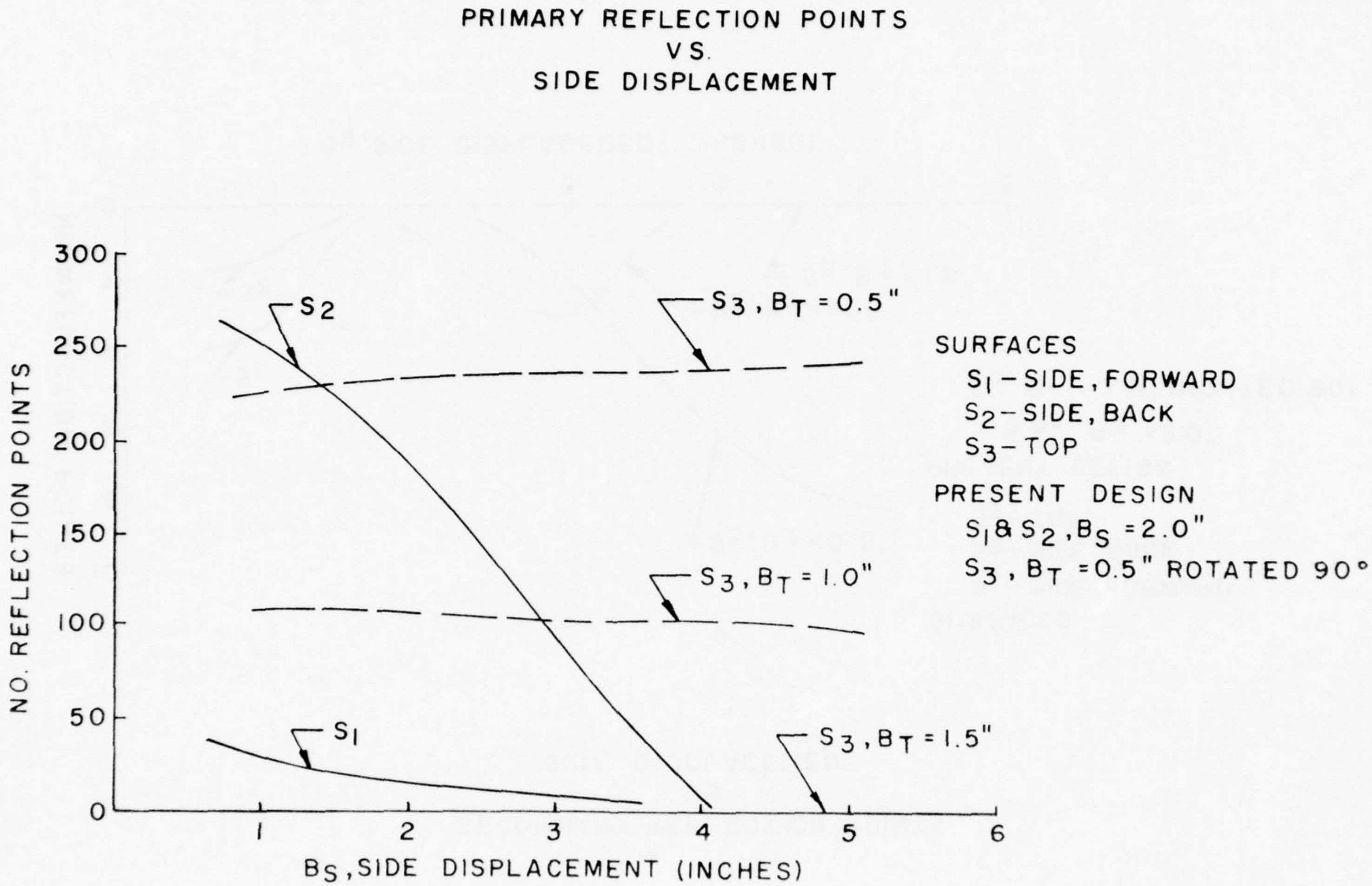


Figure 24. Primary order reflection points as a function of side and top window displacements.

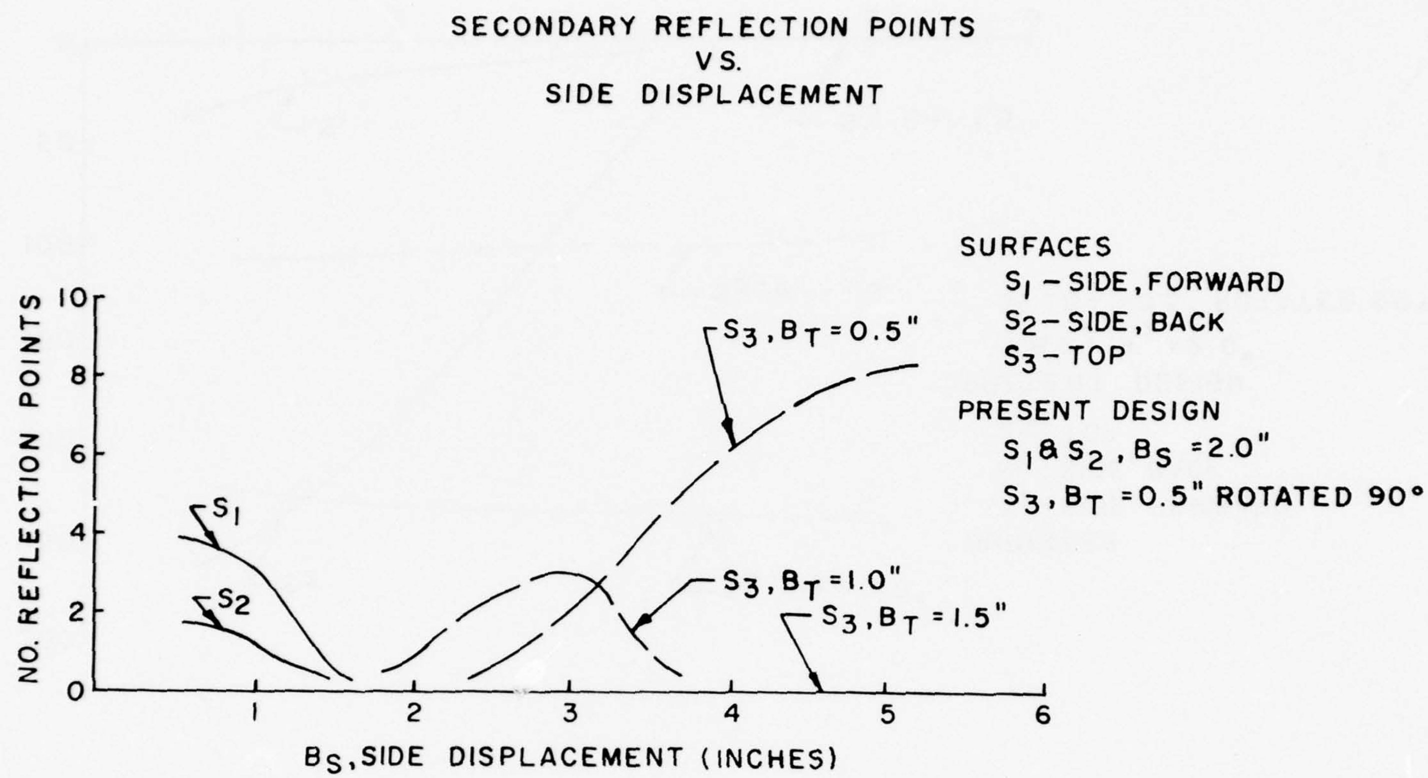


Figure 25. Secondary order reflection points as a function of side and top window displacements.

RECOMMENDATIONS FOR FURTHER RESEARCH

The following is recommended for further research:

1. Test the modified LGC design with a 4-inch side window displacement and a 1.5-inch top window displacement in the rotated mode, on a mockup of the Model YAH-64 Advanced Attack Helicopter available at USAHEL for such purposes.

2. Investigate combinations of other window shapes with zero Gaussian curvatures (i.e., curvature in only one direction) along with the cylindrical shape. The locus of external glint angles from any such combination will form a line on a plot of elevation and azimuth for a given sun direction.

3. Expand the analysis techniques described in the report to the computation of internal glare reflections from the instrument panel decals and lights. This is easily accomplished by modifying the attached computer program, DRWR, to consider reflected rays which originate from the instrument panel area.

4. Experimentally determine the correlation between the measure of optical distortions developed for this report, and the visual performance of the pilot. In particular, the limiting value of optical distortion beyond which pilot-vision is seriously hindered should be determined.

5. Develop further the relationship between the external glint and the tactical threat by enemy forces. In particular, the use of zero Gaussian curvature surfaces (such as cylindrically shaped windows) results in a glint pattern which has no solid angle. The objective would be a performance criteria to weight the glint pattern that is produced by a canopy design.

6. Investigate further the use of mathematical optimization techniques to design an optimum configuration by computer for the transparent surfaces of the canopy. The design would minimize both glint and glare in accordance with some performance measure, while maintaining few optical distortions.

CONCLUSION

A computer study of the low glare canopy (LGC) design for the Model YAH-64 Advanced Attack Helicopter has been completed by the USAHEL. The study employed computer programs developed by USAHEL to compute point-wise measures of three important factors determining canopy performance. The factors are (1) the internal glare, (2) the external glint and (3) the optical distortions exhibited by the design. The results of the study are determined that certain modifications to the present LGC design will reduce

the internal glare with only slight increases in external glint and optical distortions.

The modifications to the present LGC design suggested for further study are (1) increase the side window displacement from the plane of the frame vertices to 4 inches, (2) rotate the top window 90 degrees and (3) increase the top window displacement to 1.5 inches. The modified design increases the angular span over which external glint may appear. However, the glint does not appear in a solid angle and is judged not to be a tactical disadvantage. The optical distortions are increased on the top window in the region directly above the pilot. However, the distortions are not increased on the remainder of the windows at least to a degree noticeable by the method of measure used in this report.

APPENDIX A

SOLAR REFLECTIONS

The equations used in the computations are discussed in this section. The elevation and azimuth angles of the sun-position and the reflected direction are measured from the cartesian coordinate system of the aircraft. The y-axis is directed along the longitudinal axis of the aircraft from nose to aft and the coordinate values follow the station-marks. The z-axis is directed vertically and the coordinate values are the level-marks. The x-axis is orthogonal to the other two axes and directed toward the left-hand side of the aircraft (facing forward) for a right-handed coordinate system. In the following, we consider the specification of the sun-position and the computations of the specular reflection from the canopy surface and the reflected direction.

a. Specification of the Sun-Position.

The sun-position is specified by the angles of elevation (α) and azimuth (β). The elevation is the angle between the positive z-axis of the aircraft and the straight-line from the aircraft to the sun. The azimuth is the angle between the positive y-axis and the projection of the aircraft-sun line into the x-y plane. The directional cosines (a_s, b_s, c_s) of the incident sunlight are:

$$a_s = \sin\alpha \sin\beta \tag{1}$$

$$b_s = \sin\alpha \cos\beta$$

$$c_s = -\cos\alpha$$

b. Specular Reflection of the Sunlight From the Canopy Surface.

The angles that the specular reflection and the incident sunlight are to the normal of the canopy surface are equal in value and opposite in sign. The reflection lies in the plane defined by the sunlight and the surface normal (Appendix A, ref 4). Furthermore, the angle between the sunlight and the normal of the exterior surface of the canopy must be acute (less than 90 degrees) for reflection to occur. The dot product (Q) between the directional cosines of the sunlight (a_s, b_s, c_s) and the surface normal (a_n, b_n, c_n); i.e.,

$$Q = a_s a_n + b_s b_n + c_s c_n, \tag{2}$$

must be greater than zero, $Q > 0$. Here, the surface normal is directed into the cockpit. The directional cosines of the reflected ray (a_n, b_n, c_n) is given by (Appendix A, ref 2).

$$a_r = a_s - 2a_nQ, \tag{3}$$

$$b_r = b_s - 2b_nQ,$$

$$c_r = c_s - 2c_nQ.$$

The same equations apply to the computations for cylindrical surfaces. The directional cosines of the surface normal (a_n, b_n, c_n) is a function of the surface position (x,y,z) where the particular ray of sunlight reaches the surface. It is a function also of the radius of the cylinder (r_c), and the origin (x_o, y_o, z_o) and directional cosines (a_o, b_o, c_o) of the cylinder-axis (Appendix A, ref 3).

c. Angular Coordinates of the Reflected Ray

The elevation (α_r) and azimuth (β_r) of the reflected ray are computed from the direction cosines (a_r, b_r, c_r) of equations (3), and the inverse of equations (1); i,e.,

$$\alpha_r = \text{Acos}\ (c_r) \tag{4}$$

$$\beta_r = \text{Asin}\ (a_r/\sin \alpha_r)$$

APPENDIX B

OPTICAL DISTORTIONS

The computation of point-wise measures of optical distortions and transmittances are briefly discussed in this section. The program first determines a grid of equally spaced surface points on the windows of the canopy by the same method described in Appendix A for external glint. The program then computes the directional cosines of the straight line ray from the pilot's nominal eye position to the surface point using the coordinates of the line end positions.

The transmittance and lateral magnification is computed by tracing the ray through the window to the outside. Consider a ray from the pilot's eye position to the window surface point (x_s, y_s, z_s). The ray is refracted by its passage through the window surface into the material. The directional cosines of the refracted ray (a_r, b_r, c_r) are determined as a function of those of the incident ray (a_s, b_s, c_s) and the surface normal (a_n, b_n, c_n) by Snell's Law,

$$a_r = a_{s/n} + a_n q_s, \tag{1}$$

$$b_r = b_{s/n} + b_n q_s,$$

$$c_r = c_{s/n} + c_n q_s.$$

The parameter, n, is the index of refraction of the window material. The factor q_s is given by:

$$q_s = \frac{1}{n} Q_s - Q_r, \text{ where}$$

$$Q_s = -(a_s \cdot a_n + b_s \cdot b_n + c_s \cdot c_n), \text{ and}$$

$$Q_r = \frac{1}{n} (n^2 - 1 + Q^2) 1/2.$$

The transmittance (T_I) of the refracted ray at the internal surface is computed from the angles of incidence (θ_γ) and refraction (θ_r) using techniques already described (Appendix A, ref 4). The angles are given by:

$$\theta_\gamma = A\cos(\theta_s), \text{ and} \tag{2}$$

$$\theta_r = A\cos(\theta_r).$$

The refracted ray is next traced through the window material to the outer surface using the surface point as the starting point of the refracted ray. The equations for the intercept of a known ray with a planar surface are described elsewhere (Appendix A, ref 4). The outer surface of the window is assumed to have the same surface normal (a_n, b_n, c_n), but the edge vertex (x_e^1, y_e^1, z_e^1) is displaced outward by the window thickness (t)

The coordinates of the edge vertex of the outer window surface are given by:

$$x_e^1 = x_e - a_n t, \tag{3}$$

$$y_e^1 = y_e - b_n t,$$

$$z_e^1 = z_e - c_n t.$$

in terms of the inner surface edge vertex, the surface nomal and the window thickness. Substituting equations (3) into the appropriate equations (Appendix A, ref 4) gives the straight line distance (R) between the internal surface point and the intersection of refracted ray with the external surface,

$$R = (a_n(x_s - x_e) + b_n(y_s - y_e) + c_n(z_s - z_e) + t)/Q_r. \tag{4}$$

The equations for the interception point of a ray specified by a known origin and directional cosines with a cylindrical surface are described elsewhere (Appendix A, ref 5). The origin and directional cosines of the cylindrical axis for the outer surface is assumed to be the same as that for the inner surface. However, the cylindrical radius (r_c^1) is assumed to be increased by the window thickness (t); i.e., $r_c^1 = r_c + t$. The substitution of the outer surface radius into the appropriate equations gives the straight line distance along the refracted ray from the inner surface point to the outer surface point.

The intersection point (x_o, y_o, z_o) of the refracted ray with the outer window surface is given in terms of the straight line distance,

$$x_o = x_s + a_r R, \tag{5}$$

$$y_o = y_s + b_r R,$$

$$z_o = z_s + c_r R.$$

The ray transmittance through the material (T_m) is determined by the material coefficient of absorption (α_m) as:

$$T_m = \mathrm{EXP}(-\alpha_m \cdot R). \tag{6}$$

The transmitted ray is refracted at the external window surface. The directional cosines (a_o, b_o, c_o) of the refracted ray are determined by Snell's Law,

$$a_o = na_r + a_n q_o, \tag{7}$$

$$b_o = nb_r + b_n q_o,$$

$$x_o = nc_r + c_n q_o.$$

The directional cosines (a_n, b_n, c_n) are of the surface normal at the point (x_o, y_o, z_o). The factor q_o is given by:

$$q_o = nQr^1 - Q_o, \text{ where}$$

$$Qr^1 = -(a_r \cdot a_n + b_r \cdot b_n + c_r \cdot c_n), \text{ and}$$

$$Q_o = (1+n^2 (1-Q^1{}_r{}^2))^{1/2}$$

The transmittance (T_o) of the refracted ray at the outer window surface is computed from the angles of incidence (θ^1_i) and refraction (θ_o), where:

$$\theta^1_i = A_{\cos} (Q_r{}^1), \text{ and} \tag{8}$$

$$\theta_o = A\cos (Q_o).$$

However, the transmitted ray is refracted only if the factor Q_o is less than or equal to unity; i.e., $Q_o \leq 1$. In this case, the angle of incidence is less than or equal to the critical angle and the transmittance is greater than zero.

The material transmittance (T) for the passage of the ray through the material is given by,

$$T = T\gamma \cdot T_m \cdot T_o. \tag{9}$$

The lateral magnification (M_o) for the external ray compared to the internal ray is given by (ref 2, p.152),

$$M_o = A\cos (a_o \cdot a_s + b_o \cdot b_s + c_o \cdot c_s). \tag{10}$$

The optical distortion is a measure of the change of the lateral magnification over the effective field of view (ref 2, p.152). The optical distortion may be computed for each window surface point by using the above ray as a principal ray. We arbitrarily consider a 4-degree cone of vision centered at the pilot's position and about the principal ray.

A family of subsidary rays is constructed for the cone in such a manner that the solid angles contained by adjacent rays are equal. The lateral magnification (M_i) is computed for each one of the subsidary rays by the ray tracing method outlined above. The optical distortion (m_d) is arbitrarily defined as the square-root of the sum of the squares of the differences between the magnification for the principal ray (M_o) and each subsidary ray (M_i), divided by the number of rays in the cone. The equation is:

$$m_d = \left[\sum_{\varepsilon=1}^{N} (M_o - M_i)^2 / N \right]^{1/2} \qquad (11).$$

APPENDIX C

COMPUTER PROGRAMS

The computer programs are programmed for the CDC 7500 computer batch-job system in Fortran IV language (1,3). The subroutines which are common to all three programs are listed first. The subroutines unique to each program follow along with the program listing.

SUBROUTINES COMMON TO ALL THREE PROGRAMS

The subroutines common to all three programs are those used to read in frame data and compute the corresponding surface normals, and those controlling the computer graphics output. The subroutine are:

1. READV - reads in canopy frame data into common storage from frame data file. Called by main program.

2. NORML - computes surface normal for planar surface segments of canopy and plane of frame vertices for cylindrical surfaces. Called by main program.

3. DRAW - subroutine establishes drawing file for graphic picture of side, top, and front views of canopy frame. Called by COMPQ in programs DRWG and DRWE, and by DRV in DRWR.

4. EMARK and ETIC - subroutines compute pilot's eye positions in drawing file. Called by DRAW.

5. LINS
LINF
LINT - subroutines compute frame positions in drawing file. Called by DRAW.

6. BELT
PLEM - subroutines establish drawing file in form visible by Calcomp drawing routines. Called by DRAW and routines 4 and 5 above.

7. DRW - subroutine calls on Calcomp routines (see item 9 below) for drawing canopy side, top, and front views using established drawing file. Called by COMPQ in programs DRWG and DRWE and by DRV in DRWR.

8. DRWP - subroutine calls on Calcomp routines (item 9) for drawing surface points on canopy frame drawing. Called by COMPQ in programs DRWG and DRWE, and by DRV in DRWR.

9. PLTBEG
PLTSCA
PLTSYM
PLTDTS
PLTPGE - subroutines for processing Calcomp drawing (ref 3).

INTERNAL GLARE

The subroutines peculiar to this program are listed below. The list does not include those routines described elsewhere (4,5). A copy of the program is attached.

1. DRWR - main program controlling read in of canopy frame data, computation of surface normal and indexing process for computing internal reflections.

2. DRV - subroutine reads in parameters for incrementing radius of cylindrical windows, calls for computation of internal glare and controls computer graphics output. Called by DRWR.

EXTERNAL GLINT

The subroutines are listed below followed by the program.

1. DRWG - main program controlling read in of canopy frame data, computation of surface normals and indexing processes for reflection computations.

2. DRV - subroutine reads in parameters for incrementing radius of cylindrical windows, specifies sun angles for which reflections are to be computed, and calls for computation of reflected directions as a function of sun position for each cylinder radius considered. Called by DRWG.

3. COMPQ - subroutine calls for computation of reflected directions as a function of sun angle and drawings of canopy frame with reflection points and plots of the reflection directions for each cylinder radius considered. Called by DRV.

4. DRVO - subroutine established grid of equally spaced surface points on canopy surface and computes reflection angles for the specified sun position. Called by COMPQ.

5. INTCY - subroutine computes intersection point of straight line with cylindrical surface. Called by DRVO to establish grid of surface points.

6. TRSCY - subroutine converts coordinates of a cylindrical coordinate system into a rectangular system. Called by INTCY when testing an intersection point of a line with a cylindrical surface against the frame edges of the surface.

OPTICAL DISTORTIONS

The subroutines are listed below followed by the program.

1. DRWE - main program controlling the read in of canopy frame data, computation of surface normals and indexing processes for computations.

2. DRV - subroutine reads in parameters for incrementing radius of cylindrical windows and calls for computations for each cylindrical radius considered. Called by DRWE.

3. COMPQ - subroutine calls for the computation of the optical measure and the drawings showing the distribution of the optical measures on the canopy frame for the specified cylindrical radius. Called by DRV.

4. CANL - subroutine establishes grid of equally spaced surface points on canopy surface and calls for computation of optical measures for the angular direction to each surface point in turn. Called by COMPQ.

5. CALC - subroutine determines the transmittance and optical distortions for the specified angular direction. Called by CANL.

6. INTEC - subroutine determines the intersection point of a straight line ray, from the pilot's normal eye position, with a planar surface and whether or not the point lies within the planar segment. Called by CALC.

7. INTCY - subroutine computes intersection point of straight line with cylindrical surface and determines whether point is enclosed within the cylindrical segment. Called by CALC.

8. TRSCY - subroutine converts coordinates of a cylindrical coordinate system into a rectangular system. Called by INTCY when testing an intersection point of a line with a cylindrical surface against the frame edges of the surface.

9. WKTEC - subroutine computes the exit position and directional cosines of a ray passing through a planar surface, along with the optical transmittance for the ray. Called by CALC.

10. WKTCY - subroutine computes the exit position and directional cosines of a ray passing through a cylindrical surface, along with the optical transmittance. Called by CALC.

11. TRANS - computes the transmittance for a ray passing through a dielectric surface from Fresnel's Law. Called by WKTEC and WKTCY.

```
SMYTH,STMFZ,T1000.
ACCOUNT,HE***.
BEGIN,ATTACH,PLOTLIB.
REQUEST,TAPE13,*PF.
FTN(SL,R).
MAP,ON.
LGO.
BEGIN,PLOT,CALCOMP,TAPE13.
EXIT.
BEGIN,PLOT,CALCOMP,TAPE13.
EXIT.
      PROGRAM DRWR(INPUT,OUTPUT,TAPE4,TAPE13,TAPE2=INPUT)
C MAINLINE, RAY TRACING FOR PILOT
C 3 DIMENSIONAL FLAT/CYLINDRICAL CANOPY WITH OBSTRUCTIONS
      COMMON/LB/STRG(4)
      DATA STRG/"INTERNAL","GLARE","REFLECTION",">"/
      CALL READV
      CALL NORML
      CALL DRV
      STOP
      END
      SUBROUTINE DRV
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     C,8)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     00),CE(10),RC(10)
      COMMON/CON/IR,NSR(100,10)
      COMMON/LR/B,RCC,B1,RCC1
      DIMENSION AW(9),AR(4)
      DATA AW(9),AR(4)/2*1H>/
      NCO=NC+1
      READ(2,800)
      READ(2,801)XH,XP,YP,ZP,AN,BN,CN,YA,ZA
      READ(2,801)XH1,XP1,YP1,ZP1,AN1,BN1,CN1,YA1,ZA1
      READ(2,800)
      READ(2,802)BO,BM,DB,NB
      READ(2,800)
      READ(2,802)BO1,BM1,DB1,NB1
      READ(2,800)
      READ(2,803)KR
  800 FORMAT()
  801 FORMAT(2X,4(F10.4,2X)/6(2X,F10.4))
  802 FORMAT(2X,3(F10.4,2X),I2)
  803 FORMAT(2X,I2)
      DO 20 IC=1,KR
      KRR=IC+1
      IR=IC
      B=BO-DB
      DO 10 I=1,NB
      B=B+DB
      RCC=.5*(XH**2+B**2)/B
      DO 3 IJ=1,2
      RC(IJ)=RCC
      XC(IJ)=-(XP-(RCC-B)*AN)*((-1)**IJ)
      YC(IJ)=YP-(RCC-B)*BN+YA
      ZC(IJ)=ZP-(RCC-B)*CN+ZA
    3 CONTINUE
      B1=BO1-DB1
      DO 10 K=1,NB1
```

```
      B1=B1+DB1
      RCC1=.5*(XH1**2+B1**2)/B1
      RC(3)=RCC1
      XC(3)=XP1-(RCC1-B1)*AN1
      YC(3)=YP1-(RCC1-B1)*BN1+YA1
      ZC(3)=ZP1-(RCC1-B1)*CN1+ZA1
      NVLL=0
      DO 5 IK=1,KRR
      DO 5 IP=NCO,ND
    5 NSR(IP,IK)=0
      CALL DRAW
      CALL DRW(13)
      REWIND 4
      CALL CANL(NVLL)
      CALL DRWP(NVLL)
      ENCODE(73,1000,AW)B,RCC,B1,RCC1
 1000 FORMAT(2X,"SIDE WINDOW",2X,2(F10.4,2X),"TOP WINDOW",2(2X,F10.4))
      CALL PLTSYM(.125,AW,0.,600.,5.)
      ENCODE(23,1001,AR)KR
 1001 FORMAT(2X,"TOTAL REFLECTIONS",2X,I2)
      CALL PLTSYM(.125,AR,0.,600.,-7.)
      ENCODE(79,1002,AW)(IP,IP=NCO,ND)
 1002 FORMAT(2X,"SURFACE",10(4X,I3))
      CALL PLTSYM(.125,AW,0.,600.,-19.)
      YCK=0.
      DO 6 IK=1,KRR
      ENCODE(79,1003,AW)(NSR(IP,IK),IP=NCO,ND)
 1003 FORMAT(2X,"POINTS",1X,10(1X,I6))
      CALL PLTSYM(.125,AW,0.,600.,-31.-YCK)
      YCK=YCK+12.
    6 CONTINUE
      ENCODE(22,1004,AR)NVLL
 1004 FORMAT(2X,"TOTAL POINTS",2X,I6)
      CALL PLTSYM(.125,AR,0.,600.,-31.-YCK)
      CALL PLTPGE
   10 CONTINUE
   20 CONTINUE
      RETURN
      END
      SUBROUTINE CANL(NVLL)
C CONTROLS CALCULATION OF REFLECTION POINTS
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      DATA AI1,AI2/2.,2./
C INDEX PILOT VIEWING DIRECTION
C A1 ELEVATION, ANGLE FROM Z AXIS TOWARD X AXIS IN X Z PLANE
C A2 AZIMUTH, ANGLE FROM X Z PLANE TOWARD Y AXIS
C Z AXIS TOWARD UPWARD, X AXIS TOWARD LEFT FACING FRONT OF CANOPY AND Y
C TOWARD BACK OF CANOPY ALONG LONGITUDINAL AXIS OF AIRCRAFT
      A1=0.
   10 A2=AI2
   11 A2=A2-AI2
      IF(A2.GE.-90.) GO TO 15
      A1=A1+AI1
      IF(A1.GT.180.) GO TO 299
      GO TO 10
   15 CONTINUE
      IS=0
      CALL CALC(A1,A2,IS,NVLL)
```

```
      IF(IS.EQ.NA)CALL CALC(A1,A2,NA,NVLL)
      GO TO 11
  299 CONTINUE
      RETURN
      END
      SUBROUTINE CALC(A1,A2,NK,NVLL)
C PRIMARY REFLECTION ONLY, SURFACE NK TRANSMITTER ONLY
      COMMON/CAN/NT,NB,NC,NP,NA,ND,KV(100),PXV(100,8),PYV(100,8),PZV(10
     0,8)
      COMMON/PILOT/XO,YO,ZO
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      COMMON/CON/KM,NSR(100,10)
      COMMON/FACT/SX,AXO,BXO,AX1,BX1
      DIMENSION IPP(10),ASP(10),BSP(10),CSP(10),XP(10),YP(10),ZP(10),AIP
     C(10),BIP(10),CIP(10),ARP(10),BRP(10),CRP(10),RP(10)
      DATA PI/3.14159/
      A1M=A1*PI/180.
      A2M=A2*PI/180.
      AS=COS(A2M)*SIN(A1M)
      BS=SIN(A2M)
      CS=COS(A2M)*COS(A1M)
      R=1.
      XS=XO
      YS=YO
      ZS=ZO
      IPUN=0
      INK=0
   18 CONTINUE
      DO 20 IS=1,ND
      IF(IS.EQ.INK)GOTO 20
      ISK=0
      IF(IS.LE.NA)CALL INTEC(ISK,IS,XR,YR,ZR)
      IF(IS.GT.NA)CALL INTCY(ISK,IS,XR,YR,ZR)
      IF(ISK.GT.0)GOTO 25
   20 CONTINUE
      RETURN
   25 CONTINUE
      IF(IS.LE.NC)RETURN
      RX=AS*AC+BS*BC+CS*CC
      IF(RX.GT.0.)GOTO 20
      CALL COMP(ANG,RT,TT)
      T=TT*R
      R=RT*R
      IF(IS.EQ.NK)GOTO 40
      IPUN=IPUN+1
      AI=-AS
      BI=-BS
      CI=-CS
      AR=-AS+2.*RX*AC
      BR=-BS+2.*RX*BC
      CR=-CS+2.*RX*CC
      IF(IPUN.EQ.(KM+1))GOTO 30
      IF(R.LT..00001)RETURN
      IPP(IPUN)=IS
      ASP(IPUN)=AS
      BSP(IPUN)=BS
      CSP(IPUN)=CS
      XP(IPUN)=XR
      YP(IPUN)=YR
```

```
      ZP(IPUN)=ZR
      AIP(IPUN)=AI
      BIP(IPUN)=BI
      CIP(IPUN)=CI
      ARP(IPUN)=AR
      BRP(IPUN)=BR
      CRP(IPUN)=CR
      RP(IPUN)=R
      AS=-AR
      BS=-BR
      CS=-CR
      XS=XR
      YS=YR
      ZS=ZR
      GO TO 18
   30 CONTINUE
      IF(T.LT..00001)RETURN
      NVLL=NVLL+1
      DO 35 IK=1,KM
      WRITE(4,1000)XP(IK),YP(IK),ZP(IK)
 1000 FORMAT(4(F10.4))
      IPS=IPP(IK)
      NSR(IPS,IK)=NSR(IPS,IK)+1
   35 CONTINUE
      WRITE(4,1000)XR,YR,ZR,T
      NSR(IS,KM+1)=NSR(IS,KM+1)+1
      NK=IPP(1)
      RETURN
   40 CONTINUE
      INK=NK
      GO TO 18
      END
      SUBROUTINE DRWP(NVLL)
      COMMON/CON/KM,NSR(100,10)
      COMMON/FACT/SX,A0,B0,A1,B1
      REWIND 4
      DO 10 I=1,NVLL
      DO 5 IK=1,KM
      READ(4,1000)XP,YP,ZP
      XX=(YP-5.5)*SX+100.
      YY=(ZP-111.52)*SX+100.
      CALL PLTDTS(3,0,XX,YY,1,0)
    5 CONTINUE
      READ(4,1000)XR,YR,ZR,T
      IC=-ALOG10(T)+1.
      XX=(YR-5.5)*SX+100.
      YY=(ZR-111.52)*SX+100.
      CALL PLTDTS(3,IC,XX,YY,1,0)
   10 CONTINUE
 1000 FORMAT(4(F10.4))
      REWIND 4
      DO 20 I=1,NVLL
      DO 15 IK=1,KM
      READ(4,1000)XP,YP,ZP
      XX=(YP-5.5)*SX+100.
      YY=(XP+104.)*SX+433.44
      CALL PLTDTS(3,0,XX,YY,1,0)
   15 CONTINUE
      READ(4,1000)XR,YR,ZR,T
```

```
      IC=-ALOG10(T)+1.
      XX=(YR-5.5)*SX+100.
      YY=(XR+104.)*SX+433.44
      CALL PLTDTS(3,IC,XX,YY,1,0)
   20 CONTINUE
      REWIND 4
      DO 30 I=1,NVLL
      DO 25 IK=1,KM
      READ(4,1000)XP,YP,ZP
      XX=(ZP-111.52)*SX+690.42
      YY=(XP+104.)*SX+433.44
      CALL PLTDTS(3,0,XX,YY,1,0)
   25 CONTINUE
      READ(4,1000)XR,YR,ZR,T
      IC=-ALOG10(T)+1.
      XX=(ZR-111.52)*SX+690.42
      YY=(XR+104.)*SX+433.44
      CALL PLTDTS(3,IC,XX,YY,1,0)
   30 CONTINUE
      RETURN
      END
      SUBROUTINE READV
C READ IN SURFACE VERTICES
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(10
     0,8)
      COMMON/VERT/XV(200),YV(200),ZV(200),NVR(100,8)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     00),CE(10),RC(10)
      COMMON/PILOT/XO,YO,ZO
      READ(2,1000)
 1000 FORMAT()
      READ(2,1000)
      READ(2,1001)NT,NB,NC,NP,NA,ND
 1001 FORMAT(6(2X,I3))
      READ(2,1000)
      READ(2,1002)(NV(I),I=1,ND)
 1002 FORMAT(10(2X,I3))
      READ(2,1000)
      DO 10 J=1,8
      READ(2,1002)(NVR(I,J),I=1,ND)
   10 CONTINUE
      READ(2,1000)
      READ(2,1003)(XV(I),I=1,NT)
 1003 FORMAT(8(2X,F7.4))
      READ(2,1000)
      READ(2,1003)(YV(I),I=1,NT)
      READ(2,1000)
      READ(2,1003)(ZV(I),I=1,NT)
      READ(2,1000)
      READ(2,1002)NCY
      READ(2,1002)(NSC(I),I=1,NCY)
      DO 20 I=1,NCY
      KP=NSC(I)
   20 READ(2,1002)(NSP(I,K),K=1,KP)
      READ(2,1004)(XC(I),YC(I),ZC(I),AE(I),BE(I),CE(I),RC(I),I=1,NCY)
 1004 FORMAT(7(2X,F7.4))
      READ(2,1000)
      READ(2,1003)XO,YO,ZO
      RETURN
```

```
      END
      SUBROUTINE NORML
C ESTABLISH SURFACE NORMAL FOR EACH PLATE SURFACE
C SURFACE NORMALS DIRECTED TOWARD COCKPIT INTERIOR
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/VERT/XV(200),YV(200),ZV(200),NVR(100,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     Q0),CE(10),RC(10)
      COMMON/PILOT/XO,YO,ZO
      DO 10 I=1,ND
      NK=NV(I)
      DO 5 K=1,NK
      KV=NVR(I,K)
      PXV(I,K)=XV(KV)
      PYV(I,K)=YV(KV)
      PZV(I,K)=ZV(KV)
    5 CONTINUE
      K=2
    7 A1=PXV(I,K)-PXV(I,1)
      A2=PXV(I,K+1)-PXV(I,1)
      B1=PYV(I,K)-PYV(I,1)
      B2=PYV(I,K+1)-PYV(I,1)
      C1=PZV(I,K)-PZV(I,1)
      C2=PZV(I,K+1)-PZV(I,1)
      P1=SQRT(A1**2+B1**2+C1**2)
      P2=SQRT(A2**2+B2**2+C2**2)
      A=(A1*A2+B1*B2+C1*C2)/(P1*P2)
      IF(ABS(A).LT.1.) GO TO 9
      K=K+1
      IF(K.EQ.NK) GO TO 10
      GO TO 7
    9 AN=ACOS(A)
      R=1./(P1*P2*SIN(AN))
      AXN(I)=+(B1*C2-C1*B2)*R
      AYN(I)=-(A1*C2-C1*A2)*R
      AZN(I)=+(A1*B2-A2*B1)*R
   10 CONTINUE
      RETURN
      END
      SUBROUTINE INTEC(ISK,IS,XR,YR,ZR)
C DETERMINES IF RAY STRIKES CONVEX SURFACE
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      CK=AXN(IS)*AS+AYN(IS)*BS+AZN(IS)*CS
      IF(CK.GE.0.) RETURN
C RAY STRIKES SURFACE IN OUTWARD DIRECTION
      I=1
      IF(XS.EQ.PXV(IS,I).AND.YS.EQ.PYV(IS,I).AND.ZS.EQ.PZV(IS,I))I=I+1
      S=(AXN(IS)*(PXV(IS,I)-XS)+AYN(IS)*(PYV(IS,I)-YS)+AZN(IS)*(PZV(IS,I
     C)-ZS))/CK
      XR=AS*S+XS
      YR=BS*S+YS
      ZR=CS*S+ZS
      A1=PXV(IS,1)-XS
      B1=PYV(IS,1)-YS
```

AD-A078 291 HUMAN ENGINEERING LAB ABERDEEN PROVING GROUND MD F/G 1/3
A STUDY OF THE CANOPY DESIGN FOR THE ADVANCED ATTACK HELICOPTER--ETC(U)
AUG 79 C C SMYTH
UNCLASSIFIED HEL-TM-13-79 NL

2 OF 2

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```
      C1=PZV(IS,1)-ZS
      P1=XR-XS
      P2=YR-YS
      P3=ZR-ZS
      IN=NV(IS)
      DO 10 I=1,IN
      IC=I+1
      IF(I.EQ.IN) IC=1
      A2=PXV(IS,IC)-XS
      B2=PYV(IS,IC)-YS
      C2=PZV(IS,IC)-ZS
      Q=P1*(B1*C2-B2*C1)-P2*(A1*C2-C1*A2)+P3*(A1*B2-B1*A2)
      IF(Q.GT.0.)RETURN
C RAY STRIKES SURFACE ON ENCLOSED SIDE OF SURFACE EDGE
      A1=A2
      B1=B2
      C1=C2
   10 CONTINUE
C RAY STRIKES ENCLOSED SURFACE
      ISK=1
      AC=AXN(IS)
      BC=AYN(IS)
      CC=AZN(IS)
      RETURN
      END
      SUBROUTINE INTCY(ISK,IS,XR,YR,ZR)
C COMPUTES INTERSECTION POINT OF LINE WITH CYLINDER
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     0,8)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     00),CE(10),RC(10)
      COMMON/PILOT/XP,YP,ZP
C DETERMINE CYLINDERICAL SURFACE WHICH CONVEX SURFACE IS A PART OF
      DO 2 I=1,NCY
      KP=NSC(I)
      DO 2 K=1,KP
      IF(NSP(I,K).EQ.IS)GOTO 5
    2 CONTINUE
      RETURN
    5 CONTINUE
C DETERMINE INTERSECTION POINT
      XO=XC(I)
      YO=YC(I)
      ZO=ZC(I)
      RO=RC(I)
      AO=AE(I)
      BO=BE(I)
      CO=CE(I)
      ROS=SQRT((XS-XO)**2+(YS-YO)**2+(ZS-ZO)**2)
      AOO=(XS-XO)/ROS
      BOO=(YS-YO)/ROS
      COO=(ZS-ZO)/ROS
      A=AO*AS+BO*BS+CO*CS
      B=ROS*(AO*AOO+BO*BOO+CO*COO)
      A1=AS-A*AO
      A2=BS-A*BO
      A3=CS-A*CO
      B1=AOO*ROS-B*AO
```

```
      B2=BOO*ROS-B*BO
      B3=COO*ROS-B*CO
      A=A1**2+A2**2+A3**2
      B=A1*B1+A2*B2+A3*B3
      C=B1**2+B2**2+B3**2
      AB=-B/A
      AX=B**2-A*(C-RO**2)
      IF(AX.LT.O.)AX=O.
      BB=SQRT(AX)/A
      RS=AB-BB
      IF(RS.LE.O.)RS=AB+BB
      IF(RS.LE.O.)RETURN
      XR=XS+AS*RS
      YR=YS+BS*RS
      ZR=ZS+CS*RS
      R=RS*(AO*AS+BO*BS+CO*CS)+ROS*(AO*AOO+BO*BOO+CO*COO)
      X1=XO+AO*R
      Y1=YO+BO*R
      Z1=ZO+CO*R
      AC=(X1-XR)/RO
      BC=(Y1-YR)/RO
      CC=(Z1-ZR)/RO
C DETERMINES WHETHER RAY STRIKES ENCLOSED SURFACE
      XSS=XP
      YSS=YP
      ZSS=ZP
      CALL TRSCY(I,XSS,YSS,ZSS)
      XRR=XR
      YRR=YR
      ZRR=ZR
      CALL TRSCY(I,XRR,YRR,ZRR)
      P1=XRR-XSS
      P2=YRR-YSS
      P3=ZRR-ZSS
      X1=PXV(IS,1)
      Y1=PYV(IS,1)
      Z1=PZV(IS,1)
      CALL TRSCY(I,X1,Y1,Z1)
      A1=X1-XSS
      B1=Y1-YSS
      C1=Z1-ZSS
      IN=NV(IS)
      DO 10 II=1,IN
      IC=II+1
      IF(II.EQ.IN)IC=1
      X2=PXV(IS,IC)
      Y2=PYV(IS,IC)
      Z2=PZV(IS,IC)
      CALL TRSCY(I,X2,Y2,Z2)
      A2=X2-XSS
      B2=Y2-YSS
      C2=Z2-ZSS
      Q=P1*(B1*C2-B2*C1)-P2*(A1*C2-C1*A2)+P3*(A1*B2-B1*A2)
      IF(Q.GT.O.)RETURN
C RAY STRIKES SURFACE ON ENCLOSED SIDE OF SURFACE EDGE
      A1=A2
      B1=B2
      C1=C2
   10 CONTINUE
```

```
C RAY STRIKES ENCLOSED SURFACE
      ISK=1
      RETURN
      END
      SUBROUTINE TRSCY(I,XR,YR,ZR)
C CONVERTS COORDINATES IN CLINDRICAL COORDINATES INTO RECTANGULAR SPACE
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     O0),CE(10),RC(10)
      CN=SQRT(1.-CE(I)**2)
      AN=-AE(I)*CE(I)/CN
      BN=-BE(I)*CE(I)/CN
      AP=BE(I)*CN-BN*CE(I)
      BP=-(AE(I)*CN-AN*CE(I))
      CP=AE(I)*BN-AN*BE(I)
      RO=AE(I)*(XR-XC(I))+BE(I)*(YR-YC(I))+CE(I)*(ZR-ZC(I))
      XX=XC(I)+AE(I)*RO
      YY=YC(I)+BE(I)*RO
      ZZ=ZC(I)+CE(I)*RO
      R=SQRT((XR-XX)**2+(YR-YY)**2+(ZR-ZZ)**2)
      AA=(XR-XX)/R
      BB=(YR-YY)/R
      CC=(ZR-ZZ)/R
      A=AN*AA+BN*BB+CN*CC
      IF(A.GT.1.)A=1.
      IF(A.LT.-1.)A=-1.
      ANG=ACOS(A)
      Q=AP*AA+BP*BB+CP*CC
      IF(Q.LT.O.)ANG=-ANG
      XR=ANG*RC(I)
      YR=RO
      ZR=R-RC(I)
      RETURN
      END
      SUBROUTINE COMP(ANG,RT,TT)
C COMPUTES INCIDENCE ANGLE, REFLECTANCE, AND TRANSMITTANCE
C NATURAL LIGHT, ADDITION OF POLARIZATION COMPONENTS IGNORED
C XN, INDEX OF REFRACTION, TX, INTERNAL TRANSNITTANCE
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      DATA XN,TXX/1.5,.05/
      TT=0.
      RT=1.
      A=-AS*AC-BS*BC-CS*CC
      IF(A.LE.O.)RETURN
      IF(A.GT.1.)A=1.
      ANG=ACOS(A)
      ANGP= ASIN(SIN(ANG)/XN)
      CA=COS(ANG)
      SA=SIN(ANG)
      S1=SQRT(XN**2-SA**2)
      RO=(((CA-S1)/(CA+S1))**2+((CA*(XN**2)-S1)/(CA*(XN**2)+S1))**2)/2.
      TO=(1.-RO)*CA/COS(ANGP)
      CA=COS(ANGP)
      SA=SIN(ANGP)
      TX=EXP(-TXX/CA)
      S1=SQRT(XN**2-SA**2)
      RI=(((CA-S1)/(CA+S1))**2+((CA*(XN**2)-S1)/(CA*(XN**2)+S1))**2)/2.
      TI=(1.-RI)*CA/COS(ANG)
      TT=TO*TI*TX/(1.-(RI*TX)**2)
      RT=RO+RI*TT
```

```
      RETURN
      END
      SUBROUTINE DRAW
C DRAWS GRAPHIC PICTURE OF CANOPY IN THREE FOLD LAYOUT
      COMMON/DRA/MX(100),NS(100),XS(1000),YS(1000),NSY(100),NE,NX
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/PILOT/XO,YO,ZC
      COMMON/FACT/SX,AO,BO,A1,B1
      NX=0
      SX=2.122
      NSS=NC+1
      AO=-5.5
      BO=1CO.
      A1=-111.52
      B1=100.
      XX=(YO+AO)*SX+BO
      YY=(ZO+A1)*SX+B1
      CALL BELT(1,XX,YY,1,0)
      CALL EMARK(XX,YY)
      NE=1
      DO 2 I=NSS,ND
      QS=-AXN(I)
      IF((I.LE.NC.AND.QS.LT.O.).OR.(I.GT.NC.AND.QS.GT.O.))GOTO 2
C SURFACE FACES VIEWER FROM SIDE VIEW
      XX=(PYV(I,1)+AO)*SX+BO
      YY=(PZV(I,1)+A1)*SX+B1
      NE=NE+1
      MD=1
      IF(I.LE.NC.OR.I.EQ.NA)MD=4
      CALL BELT(NE,XX,YY,MD,0)
      CALL LINS(I)
    2 CONTINUE
      A1=104.
      B1=433.44
      XX=(YO+AO)*SX+BO
      YY=(XO+A1)*SX+B1
      NE=NE+1
      CALL BELT(NE,XX,YY,1,0)
      CALL EMARK(XX,YY)
      DO 3 I=NSS,ND
      QT=+AZN(I)
      IF((I.LE.NC.AND.QT.LT.O.).OR.(I.GT.NC.AND.QT.GT.O.))GOTO 3
C SURFACE FACES VIEWER FROM TOP VIEW
      XX=(PYV(I,1)+AO)*SX+BO
      YY=(PXV(I,1)+A1)*SX+B1
      NE=NE+1
      MD=1
      IF(I.LE.NC.OR.I.EQ.NA)MD=4
      CALL BELT(NE,XX,YY,MD,0)
      CALL LINT(I)
    3 CONTINUE
      AO=-111.52
      BO=690.42
      XX=(ZO+AO)*SX+BO
      YY=(XO+A1)*SX+B1
      NE=NE+1
      CALL BELT(NE,XX,YY,1,0)
```

```
      CALL ETIC(XX,YY)
      DO 10 I=NSS,ND
      QF=-AYN(I)
      IF((I.LE.NC.AND.QF.LT.O.).OR.(I.GT.NC.AND.QF.GT.O.))GOTO 10
C SURFACE FACES VIEWER FROM FRONT VIEW
      XX=(PZV(I,1)+AO)*SX+BO
      YY=(PXV(I,1)+A1)*SX+B1
      NE=NE+1
      MD=1
      IF(I.LE.NC.OR.I.EQ.NA)MD=4
      CALL BELT(NE,XX,YY,MD,0)
      CALL LINF(I)
   10 CONTINUE
      NS(NE+1)=NX+1
      RETURN
      END
      SUBROUTINE BELT(IE,X,Y,MDD,NSS)
      COMMON/DRA/MD(100),NS(100),XS(1000),YS(1000),NSY(100),NE,NP
      NP=NP+1
      NS(IE)=NP
      NSY(IE)=NSS
      MD(IE)=MDD
      XS(NP)=X
      YS(NP)=Y
      RETURN
      END
      SUBROUTINE PLEM(X,Y)
      COMMON/DRA/MD(100),NS(100),XS(1000),YS(1000),NSY(100),NE,NP
      NP=NP+1
      XS(NP)=X
      YS(NP)=Y
      RETURN
      END
      SUBROUTINE EMARK(X,Y)
C MARK EYE POSITION IN CANOPY
      X=X-10.
      Y=Y-5.
      CALL PLEM(X,Y)
      X=X+10.
      Y=Y+5.
      CALL PLEM(X,Y)
      X=X-10.
      Y=Y+5.
      CALL PLEM(X,Y)
      X=X+3.
      Y=Y-1.5
      CALL PLEM(X,Y)
      Y=Y+3.
      CALL PLEM(X,Y)
      Y=Y-14.
      CALL PLEM(X,Y)
      RETURN
      END
      SUBROUTINE ETIC(X,Y)
      Y=Y-5.
      CALL PLEM(X,Y)
      Y=Y+10.
      CALL PLEM(X,Y)
      Y=Y-5.
```

```
      CALL PLEM(X,Y)
      X=X-5.
      CALL PLEM(X,Y)
      X=X+10.
      CALL PLEM(X,Y)
      RETURN
      END
      SUBROUTINE LINS(I)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(10
     Q,8)
      COMMON/FACT/SX,A0,B0,A1,B1
      NK=NV(I)
      DO 10 K=1,NK
      K1=K+1
      IF(K.EQ.NK)K1=1
      XX=(PYV(I,K1)+A0)*SX+B0
      YY=(PZV(I,K1)+A1)*SX+B1
      CALL PLEM(XX,YY)
   10 CONTINUE
      RETURN
      END
      SUBROUTINE LINF(I)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/FACT/SX,A0,B0,A1,B1
      NK=NV(I)
      DO 10 K=1,NK
      K1=K+1
      IF(K.EQ.NK)K1=1
      XX=(PZV(I,K1)+A0)*SX+B0
      YY=(PXV(I,K1)+A1)*SX+B1
      CALL PLEM(XX,YY)
   10 CONTINUE
      RETURN
      END
      SUBROUTINE LINT(I)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/FACT/SX,A0,B0,A1,B1
      NK=NV(I)
      DO 10 K=1,NK
      K1=K+1
      IF(K.EQ.NK)K1=1
      XX=(PYV(I,K1)+A0)*SX+B0
      YY=(PXV(I,K1)+A1)*SX+B1
      CALL PLEM(XX,YY)
   10 CONTINUE
      RETURN
      END
      SUBROUTINE DRW(IUNIT)
      COMMON/DRA/MD(100),NS(100),XS(1000),YS(1000),NSY(100),NE,NP
      COMMON/LB/STRG(4)
      COMMON/DG/XP(100),YP(100)
      DIMENSION LABEL(4)
      DATA LABEL/"SMYTH","B520","X3654","HE379"/
C PROGRAM COMPUTES LAYOUT ON 1024 UNITS FITTED TO 25 INCHES
CBY 25 INCHES DISPLAY SHEET
      CALL PLTBEG(25.,25.,1.,IUNIT,LABEL)
      CALL PLTSCA(5.,5.,200.,0.,40.96,40.96)
```

```
      CALL PLTSYM(.25,STRG,0.,201.,1.)
      DO 10 IE=1,NE
      MDD=MD(IE)
      NSS=NSY(IE)
      N1=NS(IE)
      N2=NS(IE+1)-N1
      DO 5 I=1,N2
      XP(I)=XS(N1+I-1)
      YP(I)=YS(N1+I-1)
    5 CONTINUE
      CALL PLTDTS(MDD,NSS,XP,YP,N2,0)
   10 CONTINUE
      RETURN
      END
C AAH CANOPY DATA
C NUMBER OF VERTICES, SURFACES--CONSTRAINT, FLAT, AND CYLINDRICAL
  166   16   56   58   59   64
C NO. VERTICES PER SURFACE
    4    4    4    4    4    4    4    4    4    4
    4    5    5    4    4    4    4    4    4    4
    4    4    4    4    4    7    7    7    7    4
    4    6    4    4    4    4    4    4    4    5
    4    4    5    7    7    7    7    4    4    4
    4    4    4    4    4    4    4    4    8    6
    6    6    6    4
C VERTICE ASSIGNED TO EACH SURFACE
  089  090  066  121  125  129  133  135  139  143
  145  149  153  157  137  145  001  002  003  004
  007  001  005  012  011  021  015  028  022  032
  029  033  110  035  036  111  038  039  038  109
  040  041  112  053  047  060  054  061  061  089
  094  093  100  099  098  087  077  081  101  068
  071  094  100  085
  117  114  115  122  126  130  134  136  140  144
  146  150  154  158  136  148  002  003  004  005
  014  007  004  014  012  020  016  027  023  031
  030  034  109  036  037  112  039  038  111  111
  041  110  110  052  048  059  055  064  062  090
  089  094  095  100  099  098  078  082  102  069
  072  093  099  086
  114  115  119  123  127  131  130  137  141  140
  147  151  166  159  162  163  009  010  011  012
  012  005  003  008  009  019  017  026  024  030
  031  109  035  043  044  044  046  034  109  037
  045  112  042  051  049  058  056  063  063  066
  065  070  071  076  075  074  079  083  103  070
  073  092  098  087
  090  066  065  124  128  132  129  138  142  139
  148  152  155  160  161  164  008  009  010  011
  005  002  002  009  010  018  018  025  025  029
  032  110  042  042  043  037  045  033  034  036
  046  045  043  050  050  057  057  062  064  065
  070  069  076  075  074  088  080  084  104  065
  074  091  097  088
  0    0    0    0    0    0    0    0    0    0
  0    165  156  0    0    0    0    0    0    0
  0    0    0    0    0    017  019  024  026  0
  0    041  0    0    0    0    0    0    0    035
  0    0    044  049  051  056  058  0    0    0
```

```
0    0    0    0    0    0    0    0    105  066
075  090  096  0
0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    016  020  023  027  0
0    40   0    0    0    0    0    0    0    0
0    0    0    048  052  055  059  0    0    0
0    0    0    0    0    0    0    0    106  067
076  089  095  0
0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    015  021  022  028  0
0    0    0    0    0    0    0    0    0    0
0    0    0    047  053  054  060  0    0    0
0    0    0    0    0    0    0    0    107  0
0    0    0    0
0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    0    0
0    0    0    0    0    0    0    0    108  0
0    0    0    0
C VERTICE X-POSITION
     2.00      2.00      2.00      2.00      2.00      2.00      2.00     -2.00
    -2.00     -2.00     -2.00     -2.00     -2.00     -2.00     19.06     16.70
    14.25     12.90     11.20     14.76     17.42    -18.00    -17.60    -13.84
   -13.30    -13.24    -15.96    -17.96      8.50    -11.50    -12.04      9.08
    19.63     19.63     11.46     11.46     11.46     19.63     19.63    -19.63
   -19.63    -11.46    -11.46    -11.46    -19.63    -19.63     19.16     18.84
    14.22     13.10     11.24     14.78     17.50    -17.90    -17.60    -14.00
   -13.30    -13.26    -15.96    -17.96      8.56    -11.48    -12.14      9.16
    23.08     20.92     18.08     13.72     22.72     23.28     23.20     13.60
    13.00     15.16     16.36     22.84     16.72    -16.72    -14.28     14.28
    13.60    -13.60     -9.20      9.20     10.56    -10.56    -11.56     11.56
   -23.08    -20.92    -16.08    -13.72    -22.72    -23.28    -23.20    -13.60
   -13.00    -15.16    -16.36    -22.84     19.63     13.26     11.46    -11.46
   -13.26    -19.63    -12.00     12.00     13.26    -11.46     13.26    -11.46
   -23.75     -4.        4.       23.75     -4.      -23.75      4.       23.75
    24.       36.       36.       24.      -36.      -24.      -24.      -36.
    26.      104.      104.       26.       26.      104.       67.6      61.
    61.       67.6    -104.      -26.      -26.     -104.     -104.      -26.
   -61.      -67.6     -67.6     -61.      -46.      -24.      -22.      -56.
    24.       46.       56.       22.      -10.       10.       10.      -10.
    61.       61.      -61.      -61.      -56.       56.
C VERTICE Y-POSITION
    57.50     57.50     68.37     71.57     58.98     58.98     60.30     57.50
    57.50     68.37     71.57     58.98     58.98     60.30     84.66     82.92
    83.46     86.98     98.18     98.66     96.24     84.66     82.92     83.46
    86.98     98.18     98.66     96.24     87.48     87.48     97.56     97.56
    98.45    103.49    100.92    110.92    115.61    121.40    121.50     98.45
   103.49    100.92    110.92    115.61    121.40    121.50    144.26    142.52
   142.54    146.00    157.52    158.40    156.32    144.26    142.52    142.54
   146.00    157.52    158.40    156.32    148.00    148.00    156.66    156.66
    59.20     59.20     70.14    108.42    110.90     69.78    116.49    113.25
   139.69    156.97    156.97    140.09     58.30     58.30     67.18     67.18
    69.57     69.57    108.01    108.01    112.13    112.13    145.44    145.44
    59.20     59.20     70.14    108.42    110.90     69.78    116.49    113.25
   139.69    156.97    156.97    140.09    115.52    115.52    114.82    114.82
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```
    115.52    115.52    113.01    113.01    103.49    103.49    121.40    121.40
     57.5        5.5       5.5      57.5       5.5      57.5       5.5      57.5
     59.2       65.2    132.61    158.6       65.2      59.2    158.6     132.61
    186.61    191.61    226.61    236.61    186.61    191.61    189.61    189.61
    180.61    180.61    191.61    186.61    236.61    226.61    191.61    186.61
    189.61    189.61    180.61    180.61    214.61    214.61    214.61    214.61
    214.61    214.61    214.61    214.61    198.61    198.61    198.61    198.61
    198.61    224.61    198.6     224.61    214.61    214.61
C VERTICE Z-POSITION
    131.81    138.66    146.27    141.77    133.97    133.97    132.83    131.81
    138.66    146.27    141.77    133.97    133.97    132.83    128.40    130.34
    145.26    148.54    148.08    136.54    127.96    128.40    130.34    145.26
    148.54    148.08    136.54    127.96    118.61    118.61    156.00    156.00
    129.20    148.00    157.58    160.51    160.88    139.20    129.20    129.20
    148.00    157.58    160.51    160.88    139.20    129.20    147.56    149.40
    164.26    167.64    167.68    156.20    147.54    147.56    149.40    164.26
    167.64    167.68    156.20    147.54    137.86    137.86    175.68    175.68
    129.05    141.41    154.80    172.40    150.68    130.85    146.36    174.59
    179.28    179.24    176.40    150.80    143.52    143.52    154.40    154.40
    156.72    156.72    175.15    175.15    177.93    177.93    182.12    182.12
    129.05    141.41    154.80    172.40    150.68    130.85    146.36    174.59
    179.28    179.24    176.00    150.80    152.54    152.54    159.03    159.03
    152.54    152.54    175.79    175.79    148.00    148.00    139.20    139.20
    144.2      129.1    129.1     144.2     122.1     127.05    122.1     127.05
    124.12    124.12    124.12    124.12    124.12    124.12    124.12    124.12
    142.52    140.52    140.52    142.52    132.12    132.92    132.52    132.52
    111.52    111.52    140.52    142.52    142.52    140.52    132.92    132.12
    132.52    132.52    111.52    111.52    147.92    147.92    178.52    178.52
    147.92    147.92    178.52    178.52    181.52    181.52    221.52    221.52
    111.52    132.52    111.52    132.52    157.92    157.92
C CYLINDRICAL DATA
     3
     2     2     1
    60    61
    62    63
    64
    -31.9954 135.89    147.4713 .0        .9805     .1968      55.9916
     31.9954 135.89    147.4713 .0        .9805     .1968      55.9916
     0.      133.6172  139.3729 .0      -.9837    -.1796      42.9375
C PILOT EYE POSITION
    -1.5     142.33    171.2
C CANOPY EDGES FITTED TO CYLINDRICAL SIDES
    20.783        17.875     130.91      161.175
     .9592          .0          .2828       4.98          .9995
     11.25        0.         126.175     180.135
     0.           -.1796      .9837      0.         0.
C CANOPY DISPLACEMENT OF CYLINDRICAL SIDES FROM FLAT WINDOW
    1.           5.          1.          1
C TOP WINDOW
     .5          2.5          .5         1
C ORDER OF REFLECTIONS
    1
```

```
SMYTH,STMFZ,T1000.
ACCOUNT,HE***.
BEGIN,ATTACH,PLOTLIB.
REQUEST,TAPE13,*PF.
FTN(SL,R).
MAP,ON.
LGO.
BEGIN,PLOT,CALCOMP,TAPE13.
EXIT.
BEGIN,PLOT,CALCOMP,TAPE13.
EXIT.
      PROGRAM DRWG(INPUT,OUTPUT,TAPE4,TAPE13,TAPE2=INPUT)
C MAINLINE, GLINT ACCEPTANCE ANGLES
C THREE DIMENSIONAL FLAT/CYLINDRICAL CANOPY INCREMENTAL
      COMMON/LB/STRG(4)
      DATA STRG/"EXTERNAL","GLINT","REFLECTION",">"/
      CALL READV
      CALL NORML
      CALL DRV
      STOP
      END
      SUBROUTINE DRV
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),
     QPZV(100,8)
      COMMON/SUN/KINC,DRKI,AU,BU,CU
      COMMON/LR/AW(9),AR(15)
      AW(9)=1H>
      AR(15)=1H>
      READ(2,800)
      READ(2,801)XH,XP,YP,ZP,AN,BN,CN,YA,ZA
      READ(2,801)XH1,XP1,YP1,ZP1,AN1,BN1,CN1,YA1,ZA1
      READ(2,800)
      READ(2,802)B0
      READ(2,800)
      READ(2,802)B01
      READ(2,800)
  800 FORMAT()
  801 FORMAT(2X,4(F10.4,2X)/6(2X,F10.4))
  802 FORMAT(2X,3(F10.4,2X),I2)
C ANS, BNS SUN'S DIRECTIONAL ANGLES
C ANS ELEVATION FROM Z- AXIS, BNS AZIMUTH FROM X-AXIS TOWARD Y-AXIS
C START SUN ANGLES, ANS--5 DEGREES, BNS--0 DEGREES
      KINC=2
      KFULL=180
      DRKI=KFULL/KINC
      B=B0
      RCC=.5*(XH**2+B**2)/B
      CALL COMPR(1,2,RCC,B,XP,YP,ZP,AN,BN,CN,YA,ZA)
      B1=B01
      RCC1=.5*(XH1**2+B1**2)/B1
      CALL COMPR(3,3,RCC1,B1,XP1,YP1,ZP1,AN1,BN1,CN1,YA1,ZA1)
      ENCODE(75,995,AW)B,RCC,B1,RCC1
  995 FORMAT(2X,"SIDE WINDOW",2(2X,F10.4),2X,"TOP WINDOW",2(2X,F10.4))
      CALL COMPQ(1,3)
      RETURN
      END
      SUBROUTINE COMPR(IJ1,IJ2,RCC,B,XP,YP,ZP,AN,BN,CN,YA,ZA)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     00),CE(10),RC(10)
```

```
      DO 10 IJ=IJ1,IJ2
      RC(IJ)=RCC
      XC(IJ)=-(XP-(RCC-B)*AN)*((-1)**IJ)
      YC(IJ)=YP-(RCC-B)*BN+YA
      ZC(IJ)=ZP-(RCC-B)*CN+ZA
   10 CONTINUE
      RETURN
      END
      SUBROUTINE COMPQ(IJ1,IJ2)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     Q0),CE(10),RC(10)
      COMMON/SUN/KINC,DRKI,AU,BU,CU
      COMMON/SOL/NRP,NRT(10,10,20)
      COMMON/FACT/SX,A0,B0,A1,B1
      COMMON/LR/AW(5),AR(15)
      DIMENSION LABEL(4)
      DATA LABEL/"SMYTH","B520","X3654","HE379"/
      DATA PI/3.14159/
      ICC=0
      REWIND 4
      DO 9 IRU=1,KINC
      XIU=IRU-1
      ANS=XIU*DRKI+5.
      A11=ANS*PI/180.
      DO 9 KU=1,KINC
      XKU=KU-1
      BNS=XKU*DRKI
      A22=BNS*PI/180.
      AU=-SIN(A11)*COS(A22)
      BU=-SIN(A11)*SIN(A22)
      CU=-COS(A11)
      ICC=ICC+1
      DO 7 IJ=IJ1,IJ2
      IC=NSC(IJ)
      DO 3 IK=1,IC
      IQ=NSP(IJ,IK)
      CALL DRVD(IJ,IQ)
      NRT(IJ,IQ-NC,ICC)=NRP
    3 CONTINUE
    7 CONTINUE
    9 CONTINUE
      CALL DRAW
      CALL DRW(13)
      A0=-5.5
      B0=100.
      A1=-111.52
      B1=100.
      CALL DRWP(1,IJ1,IJ2)
      A1=104.
      B1=433.44
      CALL DRWP(2,IJ1,IJ2)
      A0=-111.52
      B0=690.42
      CALL DRWP(3,IJ1,IJ2)
      ICT=KINC*KINC
      CALL PLTSYM(.125,AW,0.,600.,5.)
      ENCODE(132,1020,AR)(ICC,ICC=1,ICT)
```

```
 1020 FORMAT(2X,"SUN ANGLES",20(2X,I4))
      CALL PLTSYM(.125,AR,0.,600.,-7.)
      YCK=0.
      DO 18 IJ=IJ1,IJ2
      IC=NSC(IJ)
      DO 18 IK=1,IC
      IQ=NSP(IJ,IK)
      YCK=YCK+12.
      ENCODE(132,1021,AR)IQ,(NRT(IJ,IQ-NC,ICC),ICC=1,ICT)
 1021 FORMAT(6X,21(2X,I4))
      CALL PLTSYM(.125,AR,0.,600.,-7.-YCK)
   18 CONTINUE
      CALL PLTPGE
      DO 25 IJ=IJ1,IJ2
      IC=NSC(IJ)
      DO 25 IK=1,IC
      IQ=NSP(IJ,IK)
      ENCODE(40,1022,AW)IQ
 1022 FORMAT(2X,"WINDOW",2X,I2,26X)
      CALL PLTBEG(5.,5.,1.,13,LABEL)
      CALL PLTSCA(.25,.25,0.,0.,40.,40.)
      CALL PLTAXS(10.,10.,0.,180.,0.,180.,8)
      REWIND 4
      ICC=0
      DO 21 IRU=1,KINC
      DO 21 KU=1,KINC
      ICC=ICC+1
      DO 21 IJJ=IJ1,IJ2
      ICE=NSC(IJJ)
      DO 21 IKK=1,ICE
      IQQ=NSP(IJJ,IKK)
      NRP=NRT(IJJ,IQQ-NC,ICC)
      IF(NRP.EQ.0)GOTO 21
      DO 20 I=1,NRP
      READ(4,1024)N,AVN,AWN,AN,IS,XR,YR,ZR,BATA
 1024 FORMAT(I10,3F10.4,I4,4F10.4)
      IF(IQQ.NE.IQ)GOTO 20
      XX=AVN
      YY=AWN
      CALL PLTDTS(3,ICC,XX,YY,1,0)
   20 CONTINUE
   21 CONTINUE
      CALL PLTSYM(.125,AW,0.,40.,-5.)
      CALL PLTPGE
   25 CONTINUE
      IF(IJ1.EQ.IJ2.AND.IC.EQ.1)RETURN
      ENCODE(40,1025,AW)
 1025 FORMAT(2X,"ALL SURFACES",26X)
      CALL PLTBEG(5.,5.,1.,13,LABEL)
      CALL PLTSCA(.25,.25,0.,0.,40.,40.)
      CALL PLTAXS(10.,10.,0.,180.,0.,180.,8)
      REWIND 4
      ICC=0
      DO 27 IRU=1,KINC
      DO 27 KU=1,KINC
      ICC=ICC+1
      DO 27 IJ=IJ1,IJ2
      IC=NSC(IJ)
      DO 27 IK=1,IC
```

```
      IQ=NSP(IJ,IK)
      NRP=NRT(IJ,IQ-NC,ICC)
      IF(NRP.EQ.0)GOTO 27
      DO 26 I=1,NRP
      READ(4,1024)N,AVN,AWN,AN,IS,XR,YR,ZR,BATA
      XX=AVN
      YY=AWN
      CALL PLTDTS(3,ICC,XX,YY,1,0)
   26 CONTINUE
   27 CONTINUE
      CALL PLTSYM(.125,AW,0.,40.,-5.)
      CALL PLTPGE
      RETURN
      END
      SUBROUTINE DRWP(ICS,IJ1,IJ2)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     Q0),CE(10),RC(10)
      COMMON/SUN/KINC,DRKI,AU,BU,CU
      COMMON/SOL/NRP,NRT(10,10,20)
      COMMON/FACT/SX,A0,B0,A1,B1
      REWIND 4
      ICC=0
      DO 20 IRU=1,KINC
      DO 20 KU=1,KINC
      ICC=ICC+1
      DO 15 IJ=IJ1,IJ2
      IC=NSC(IJ)
      DO 12 IK=1,IC
      IQ=NSP(IJ,IK)
      NRP=NRT(IJ,IQ-NC,ICC)
      IF(NRP.EQ.0)GOTO 12
      DO 10 I=1,NRP
      READ(4,1002)N,AV,AW,AN,IS,XR,YR,ZR,BATA
 1002 FORMAT(I10,3F10.4,I4,4F10.4)
      X1=YR
      IF(ICS.EQ.3)X1=ZR
      Y1=ZR
      IF(ICS.GE.2)Y1=XR
      XX=(X1+A0)*SX+B0
      YY=(Y1+A1)*SX+B1
      CALL PLTDTS(3,ICC,XX,YY,1,0)
   10 CONTINUE
   12 CONTINUE
   15 CONTINUE
   20 CONTINUE
      RETURN
      END
      SUBROUTINE READV
C READ IN SURFACE VERTICES
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/VERT/XV(200),YV(200),ZV(200),NVR(100,8)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     Q0),CE(10),RC(10)
      COMMON/PILOT/X0,Y0,Z0
      READ(2,1000)
 1000 FORMAT()
```

```
      READ(2,1000)
      READ(2,1001)NT,NB,NC,NP,NA,ND
 1001 FORMAT(6(2X,I3))
      READ(2,1000)
      READ(2,1002)(NV(I),I=1,ND)
 1002 FORMAT(10(2X,I3))
      READ(2,1000)
      DO 10 J=1,8
      READ(2,1002)(NVR(I,J),I=1,ND)
   10 CONTINUE
      READ(2,1000)
      READ(2,1003)(XV(I),I=1,NT)
 1003 FORMAT(8(2X,F7.4))
      READ(2,1000)
      READ(2,1003)(YV(I),I=1,NT)
      READ(2,1000)
      READ(2,1003)(ZV(I),I=1,NT)
      READ(2,1000)
      READ(2,1002)NCY
      READ(2,1002)(NSC(I),I=1,NCY)
      DO 20 I=1,NCY
      KP=NSC(I)
   20 READ(2,1002)(NSP(I,K),K=1,KP)
      READ(2,1004)(XC(I),YC(I),ZC(I),AE(I),BE(I),CE(I),RC(I),I=1,NCY)
 1004 FORMAT(7(2X,F7.4))
      READ(2,1000)
      READ(2,1003)XO,YO,ZO
      RETURN
      END
      SUBROUTINE NORML
C ESTABLISH SURFACE NORMAL FOR EACH SURFACE NORMAL
C SURFACE NORMALS DIRECTED TOWARD COCKPIT INTERIOR
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/VERT/XV(200),YV(200),ZV(200),NVR(100,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     Q0),CE(10),RC(10)
      COMMON/PILOT/XO,YO,ZO
      DO 10 I=1,ND
      NK=NV(I)
      DO 5 K=1,NK
      KV=NVR(I,K)
      PXV(I,K)=XV(KV)
      PYV(I,K)=YV(KV)
      PZV(I,K)=ZV(KV)
    5 CONTINUE
      K=2
    7 A1=PXV(I,K)-PXV(I,1)
      A2=PXV(I,K+1)-PXV(I,1)
      B1=PYV(I,K)-PYV(I,1)
      B2=PYV(I,K+1)-PYV(I,1)
      C1=PZV(I,K)-PZV(I,1)
      C2=PZV(I,K+1)-PZV(I,1)
      P1=SQRT(A1**2+B1**2+C1**2)
      P2=SQRT(A2**2+B2**2+C2**2)
      A=(A1*A2+B1*B2+C1*C2)/(P1*P2)
      IF(ABS(A).LT.1.) GO TO 9
      K=K+1
```

```
      IF(K.EQ.NK) GO TO 10
      GO TO 7
    9 AN=ACOS(A)
      R=1./(P1*P2*SIN(AN))
      AXN(I)=+(B1*C2-C1*B2)*R
      AYN(I)=-(A1*C2-C1*A2)*R
      AZN(I)=+(A1*B2-A2*B1)*R
   10 CONTINUE
      RETURN
      END
      SUBROUTINE TRSCY(I,XR,YR,ZR)
C CONVERTS COORDINATES IN CLINDRICAL COORDINATES INTO RECTANGULAR SPACE
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     00),CE(10),RC(10)
      CN=SQRT(1.-CE(I)**2)
      AN=-AE(I)*CE(I)/CN
      BN=-BE(I)*CE(I)/CN
      AP=BE(I)*CN-BN*CE(I)
      BP=-(AE(I)*CN-AN*CE(I))
      CP=AE(I)*BN-AN*BE(I)
      RO=AE(I)*(XR-XC(I))+BE(I)*(YR-YC(I))+CE(I)*(ZR-ZC(I))
      XX=XC(I)+AE(I)*RO
      YY=YC(I)+BE(I)*RO
      ZZ=ZC(I)+CE(I)*RO
      R=SQRT((XR-XX)**2+(YR-YY)**2+(ZR-ZZ)**2)
      AA=(XR-XX)/R
      BB=(YR-YY)/R
      CC=(ZR-ZZ)/R
      A=AN*AA+BN*BB+CN*CC
      IF(A.GT.1.)A=1.
      IF(A.LT.-1.)A=-1.
      ANG=ACOS(A)
      Q=AP*AA+BP*BB+CP*CC
      IF(Q.LT.0.)ANG=-ANG
      XR=ANG*RC(I)
      YR=RO
      ZR=R-RC(I)
      RETURN
      END
      SUBROUTINE DRVO(IC,IS)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     C,8)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     C0),CE(10),RC(10)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      COMMON/PILOT/XP,YP,ZP
      COMMON/SUN/KINC,DRK1,ASS,BSS,CSS
      COMMON/SOL/NRP,NRT(10,10,20)
      DATA PI/3.14159/
      NRP=0
      YS=YP+20.
   10 CONTINUE
      XS=0.
      ZS=100.
      YS=YS-5.
      IF(YS.LT.0.)RETURN
      DO 20 IA=1,180,2
      AN=IA-91
      AN=AN*PI/180.
```

```
      AS=SIN(AN)
      BS=0.
      CS=COS(AN)
      ISK=0
      CALL INTCY(IC,ISK,IS,XR,YR,ZR)
      IF(ISK.EQ.0)GOTO 20
      BATA=ASS*AC+BSS*BC+CSS*CC
      IF(BATA.LE.0.)GOTO 20
      AR=ASS-2.*AC*BATA
      BR=BSS-2.*BC*BATA
      CR=CSS-2.*CC*BATA
      IF(CR.GT.1.)CR=1.
      IF(CR.LT.-1.)CR=-1.
      AVV=ACOS(CR)
      ASN=SIN(AVV)
      IF(ASN.EQ.0.)GOTO 18
      ASN=BR/ASN
      IF(ASN.GT.1.)ASN=1.
      IF(ASN.LT.-1.)ASN=-1.
      AHH=ACOS(ASN)
      GO TO 19
   18 CONTINUE
      AHH=0.
   19 CONTINUE
      NRP=NRP+1
      AV=AVV*180./PI
      AH=AHH*180./PI
      WRITE(4,1002)NRP,AV,AH,AN,IS,XR,YR,ZR,BATA
 1002 FORMAT(I10,3F10.4,I4,4F10.4)
   20 CONTINUE
      GO TO 10
      END
      SUBROUTINE INTCY(I,ISK,IS,XR,YR,ZR)
C COMPUTES INTERSECTION POINT OF LINE WITH CYLINDER
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     C,8)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     C0),CE(10),RC(10)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      COMMON/PILOT/XP,YP,ZP
C DETERMINE INTERSECTION POINT
      XO=XC(I)
      YO=YC(I)
      ZO=ZC(I)
      RO=RC(I)
      AO=AE(I)
      BO=BE(I)
      CO=CE(I)
      ROS=SQRT((XS-XO)**2+(YS-YO)**2+(ZS-ZO)**2)
      AOO=(XS-XO)/ROS
      BOO=(YS-YO)/ROS
      COO=(ZS-ZO)/ROS
      A=AO*AS+BO*BS+CO*CS
      B=ROS*(AO*AOO+BO*BOO+CO*COO)
      A1=AS-A*AO
      A2=BS-A*BO
      A3=CS-A*CO
      B1=AOO*ROS-B*AO
      B2=BOO*ROS-B*BO
```

```
      B3=COO*ROS-B*CO
      A=A1**2+A2**2+A3**2
      B=A1*B1+A2*B2+A3*B3
      C=B1**2+B2**2+B3**2
      AB=-B/A
      AX=B**2-A*(C-RO**2)
      IF(AX.LT.0.)AX=0.
      BB=SQRT(AX)/A
      RS=AB-BB
      IF(RS.LT.0.)RS=AB+BB
      XR=XS+AS*RS
      YR=YS+BS*RS
      ZR=ZS+CS*RS
      R=RS*(AO*AS+BO*BS+CO*CS)+ROS*(AO*AOO+BO*BOO+CO*COO)
      X1=XO+AO*R
      Y1=YO+BO*R
      Z1=ZO+CO*R
      AC=(X1-XR)/RO
      BC=(Y1-YR)/RO
      CC=(Z1-ZR)/RO
C DETERMINE WHETHER RAY STRIKES ENCLOSED SURFACE
      XSS=XP
      YSS=YP
      ZSS=ZP
      CALL TRSCY(I,XSS,YSS,ZSS)
      XRR=XR
      YRR=YR
      ZRR=ZR
      CALL TRSCY(I,XRR,YRR,ZRR)
      P1=XRR-XSS
      P2=YRR-YSS
      P3=ZRR-ZSS
      X1=PXV(IS,1)
      Y1=PYV(IS,1)
      Z1=PZV(IS,1)
      CALL TRSCY(I,X1,Y1,Z1)
      A1=X1-XSS
      B1=Y1-YSS
      C1=Z1-ZSS
      IN=NV(IS)
      DO 10 II=1,IN
      IC=II+1
      IF(II.EQ.IN)IC=1
      X2=PXV(IS,IC)
      Y2=PYV(IS,IC)
      Z2=PZV(IS,IC)
      CALL TRSCY(I,X2,Y2,Z2)
      A2=X2-XSS
      B2=Y2-YSS
      C2=Z2-ZSS
      Q=P1*(B1*C2-B2*C1)-P2*(A1*C2-C1*A2)+P3*(A1*B2-B1*A2)
      IF(Q.GT.0.)RETURN
C RAY STRIKES SURFACE ON ENCLOSED SIDE OF SURFACE EDGE
      A1=A2
      B1=B2
      C1=C2
   10 CONTINUE
C RAY STRIKES ENCLOSED SURFACE
      ISK=1
```

```
      RETURN
      END
      SUBROUTINE DRAW
C DRAWS GRAPHIC PICTURE OF CANOPY IN THREE FOLD LAYOUT
      COMMON/DRA/MX(100),NS(100),XS(1000),YS(1000),NSY(100),NE,NX
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/PILOT/XO,YO,ZO
      COMMON/FACT/SX,AO,BO,A1,B1
      NX=0
      SX=2.122
      NSS=NC+1
      AO=-5.5
      BO=100.
      A1=-111.52
      B1=100.
      XX=(YO+AO)*SX+BO
      YY=(ZO+A1)*SX+B1
      CALL BELT(1,XX,YY,1,0)
      CALL EMARK(XX,YY)
      NE=1
      DO 2 I=NSS,ND
      QS=-AXN(I)
      IF((I.LE.NC.AND.QS.LT.O.).OR.(I.GT.NC.AND.QS.GT.O.))GOTO 2
C SURFACE FACES VIEWER FROM SIDE VIEW
      XX=(PYV(I,1)+AO)*SX+BO
      YY=(PZV(I,1)+A1)*SX+B1
      NE=NE+1
      MD=1
      IF(I.LE.NC.OR.I.EQ.NA)MD=4
      CALL BELT(NE,XX,YY,MD,0)
      CALL LINS(I)
    2 CONTINUE
      A1=104.
      B1=433.44
      XX=(YO+AO)*SX+BO
      YY=(XO+A1)*SX+B1
      NE=NE+1
      CALL BELT(NE,XX,YY,1,0)
      CALL EMARK(XX,YY)
      DO 3 I=NSS,ND
      QT=+AZN(I)
      IF((I.LE.NC.AND.QT.LT.O.).OR.(I.GT.NC.AND.QT.GT.O.))GOTO 3
C SURFACE FACES VIEWER FROM TOP VIEW
      XX=(PYV(I,1)+AO)*SX+BO
      YY=(PXV(I,1)+A1)*SX+B1
      NE=NE+1
      MD=1
      IF(I.LE.NC.OR.I.EQ.NA)MD=4
      CALL BELT(NE,XX,YY,MD,0)
      CALL LINT(I)
    3 CONTINUE
      AO=-111.52
      BO=690.42
      XX=(ZO+AO)*SX+BO
      YY=(XO+A1)*SX+B1
      NE=NE+1
      CALL BELT(NE,XX,YY,1,0)
```

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      CALL ETIC(XX,YY)
      DO 10 I=NSS,ND
      QF=-AYN(I)
      IF((I.LE.NC.AND.QF.LT.0.).OR.(I.GT.NC.AND.QF.GT.0.))GOTO 10
C SURFACE FACES VIEWER FROM FRONT VIEW
      XX=(PZV(I,1)+A0)*SX+B0
      YY=(PXV(I,1)+A1)*SX+B1
      NE=NE+1
      MD=1
      IF(I.LE.NC.OR.I.EQ.NA)MD=4
      CALL BELT(NE,XX,YY,MD,0)
      CALL LINF(I)
   10 CONTINUE
      NS(NE+1)=NX+1
      RETURN
      END
      SUBROUTINE BELT(IE,X,Y,MDD,NSS)
      COMMON/DRA/MD(100),NS(100),XS(1000),YS(1000),NSY(100),NE,NP
      NP=NP+1
      NS(IE)=NP
      NSY(IE)=NSS
      MD(IE)=MDD
      XS(NP)=X
      YS(NP)=Y
      RETURN
      END
      SUBROUTINE PLEM(X,Y)
      COMMON/DRA/MD(100),NS(100),XS(1000),YS(1000),NSY(100),NE,NP
      NP=NP+1
      XS(NP)=X
      YS(NP)=Y
      RETURN
      END
      SUBROUTINE EMARK(X,Y)
C MARK EYE POSITION IN CANOPY
      X=X-10.
      Y=Y-5.
      CALL PLEM(X,Y)
      X=X+10.
      Y=Y+5.
      CALL PLEM(X,Y)
      X=X-10.
      Y=Y+5.
      CALL PLEM(X,Y)
      X=X+3.
      Y=Y-1.5
      CALL PLEM(X,Y)
      Y=Y+3.
      CALL PLEM(X,Y)
      Y=Y-14.
      CALL PLEM(X,Y)
      RETURN
      END
      SUBROUTINE ETIC(X,Y)
C MARK EYE POSITION IN CANOPY
      Y=Y-5.
      CALL PLEM(X,Y)
      Y=Y+10.
      CALL PLEM(X,Y)
```

```
      Y=Y-5.
      CALL PLEM(X,Y)
      X=X-5.
      CALL PLEM(X,Y)
      X=X+10.
      CALL PLEM(X,Y)
      RETURN
      END
      SUBROUTINE LINS(I)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/FACT/SX,A0,B0,A1,B1
      NK=NV(I)
      DO 10 K=1,NK
      K1=K+1
      IF(K.EQ.NK)K1=1
      XX=(PYV(I,K1)+A0)*SX+B0
      YY=(PZV(I,K1)+A1)*SX+B1
      CALL PLEM(XX,YY)
   10 CONTINUE
      RETURN
      END
      SUBROUTINE LINF(I)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/FACT/SX,A0,B0,A1,B1
      NK=NV(I)
      DO 10 K=1,NK
      K1=K+1
      IF(K.EQ.NK)K1=1
      XX=(PZV(I,K1)+A0)*SX+B0
      YY=(PXV(I,K1)+A1)*SX+B1
      CALL PLEM(XX,YY)
   10 CONTINUE
      RETURN
      END
      SUBROUTINE LINT(I)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/FACT/SX,A0,B0,A1,B1
      NK=NV(I)
      DO 10 K=1,NK
      K1=K+1
      IF(K.EQ.NK)K1=1
      XX=(PYV(I,K1)+A0)*SX+B0
      YY=(PXV(I,K1)+A1)*SX+B1
      CALL PLEM(XX,YY)
   10 CONTINUE
      RETURN
      END
      SUBROUTINE DRW(IUNIT)
      COMMON/DRA/MD(100),NS(100),XS(1000),YS(1000),NSY(100),NE,NP
      COMMON/LB/STRG(4)
      COMMON/DG/XP(100),YP(100)
      DIMENSION LABEL(4)
      DATA LABEL/"SMYTH","B520","X3654","HE379"/
C PROGRAM COMPUTES LAYOUT ON 1024 UNITS, WHICH IS FITTED TO
C 25 INCHES BY 25 INCHES DISPLAY SHEET
      CALL PLTBEG(25.,25.,1.,IUNIT,LABEL)
```

```
      CALL PLTSCA(5.,5.,200.,0.,40.96,40.96)
      CALL PLTSYM(.25,STRG,0.,201.,1.)
      DO 10 IE=1,NE
      MDD=MD(IE)
      NSS=NSY(IE)
      N1=NS(IE)
      N2=NS(IE+1)-N1
      DO 5 I=1,N2
      XP(I)=XS(N1+I-1)
      YP(I)=YS(N1+I-1)
    5 CONTINUE
      CALL PLTDTS(MDD,NSS,XP,YP,N2,0)
   10 CONTINUE
      RETURN
      END
C AAH CANOPY DATA
C NUMBER OF VERTICES, SURFACES--CONSTRAINT, FLAT, AND CYLINDRICAL
  166   16   56   58   59   64
C NO. VERTICES PER SURFACE
    4    4    4    4    4    4    4    4    4    4
    4    5    5    4    4    4    4    4    4    4
    4    4    4    4    4    7    7    7    7    4
    4    6    4    4    4    4    4    4    4    5
    4    4    5    7    7    7    7    4    4    4
    4    4    4    4    4    4    4    4    8    6
    6    6    6    4
C VERTICE ASSIGNED TO EACH SURFACE
  089  090  066  121  125  129  133  135  139  143
  145  149  153  157  137  145  001  002  003  004
  007  001  005  012  011  021  015  028  022  032
  029  033  110  035  036  111  038  039  038  109
  040  041  112  053  047  060  054  061  061  089
  094  093  100  099  098  087  077  081  101  068
  071  094  100  085
  117  114  115  122  126  130  134  136  140  144
  146  150  154  158  136  148  002  003  004  005
  014  007  004  014  012  020  016  027  023  031
  030  034  109  036  037  112  039  038  111  111
  041  110  110  052  048  059  055  064  062  090
  089  094  095  100  099  098  076  082  102  069
  072  093  099  086
  114  115  119  123  127  131  130  137  141  140
  147  151  166  159  162  163  009  010  011  012
  012  005  003  008  009  019  017  026  024  030
  031  109  035  043  044  044  046  034  109  037
  045  112  042  051  049  058  056  063  063  066
  065  070  071  076  075  074  079  083  103  070
  073  092  098  087
  090  066  065  124  128  132  129  138  142  139
  148  152  155  160  161  164  008  009  010  011
  005  002  002  009  010  018  018  025  025  029
  032  110  042  042  043  037  045  033  034  036
  046  045  043  050  050  057  057  062  064  065
  070  069  076  075  074  088  080  084  104  065
  074  091  097  088
  0    0    0    0    0    0    0    0    0    0
  0    165  156  0    0    0    0    0    0    0
  0    0    0    0    0    017  019  024  026  0
  0    041  0    0    0    0    0    0    0    035
```

```
0     0     044   049   051   056   058   0     0     0
0     0     0     0     0     0     0     0     105   066
075   090   096   0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     016   020   023   027   0
0     40    0     0     0     0     0     0     0     0
0     0     0     048   052   055   059   0     0     0
0     0     0     0     0     0     0     0     106   067
076   089   095   0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     015   021   022   028   0
0     0     0     0     0     0     0     0     0     0
0     0     0     047   053   054   060   0     0     0
0     0     0     0     0     0     0     0     107   0
0     0     0     0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     108   0
0     0     0     0
C VERTICE X-POSITION
     2.00       2.00       2.00       2.00       2.00       2.00       2.00      -2.00
    -2.00      -2.00      -2.00      -2.00      -2.00      -2.00      19.06      18.70
    14.25      12.90      11.20      14.76      17.42     -18.00     -17.60     -13.84
   -13.30     -13.24     -15.96     -17.96       8.50     -11.50     -12.04       9.08
    19.63      19.63      11.46      11.46      11.46      19.63      19.63     -19.63
   -19.63     -11.46     -11.46     -11.46     -19.63     -19.63      19.16      18.84
    14.22      13.10      11.24      14.78      17.50     -17.90     -17.60     -14.00
   -13.30     -13.28     -15.96     -17.96       8.56     -11.48     -12.14       9.16
    23.08      20.92      18.08      13.72      22.72      23.28      23.20      13.60
    13.00      15.16      16.36      22.84      16.72     -16.72     -14.28      14.28
    13.60     -13.60      -9.20       9.20      10.56     -10.56     -11.56      11.56
   -23.08     -20.92     -18.08     -13.72     -22.72     -23.28     -23.20     -13.60
   -13.00     -15.16     -16.36     -22.84      19.63      13.26      11.46     -11.46
   -13.26     -19.63     -12.00      12.00      13.26     -11.46      13.26     -11.46
   -23.75       -4.        4.        23.75      -4.       -23.75       4.        23.75
    24.        36.        36.        24.       -36.       -24.       -24.       -36.
    26.       104.       104.        26.        26.       104.        67.6       61.
    61.        67.6     -104.       -26.       -26.      -104.      -104.       -26.
   -61.       -67.6      -67.6      -61.       -46.       -24.       -22.       -56.
    24.        46.        56.        22.       -10.        10.        10.       -10.
    61.        61.       -61.       -61.       -56.        56.
C VERTICE Y-POSITION
    57.50      57.50      68.37      71.57      58.98      58.98      60.30      57.50
    57.50      68.37      71.57      58.98      58.98      60.30      64.66      82.92
    83.46      86.98      98.18      98.66      96.24      84.66      82.92      83.46
    86.98      98.18      98.66      96.24      87.48      87.48      97.56      97.56
    98.45     103.49     100.92     110.92     115.61     121.40     121.50      98.45
   103.49     100.92     110.92     115.61     121.40     121.50     144.26     142.52
   142.54     146.00     157.52     158.40     156.32     144.26     142.52     142.54
   146.00     157.52     158.40     156.32     148.00     148.00     156.66     156.66
    59.20      59.20      70.14     108.42     110.90      69.78     116.49     113.25
   139.69     156.97     156.97     140.09      58.30      58.30      67.18      67.18
    69.57      69.57     108.01     108.01     112.13     112.13     145.44     145.44
    59.20      59.20      70.14     108.42     110.90      69.78     116.49     113.25
```

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   139.69    156.97    156.97    140.09    115.52    115.52    114.82    114.82
   115.52    115.52    113.01    113.01    103.49    103.49    121.40    121.40
    57.5       5.5       5.5      57.5       5.5      57.5       5.5      57.5
    59.2      65.2     132.61    158.6      65.2      59.2     158.6     132.61
   186.61    191.61    226.61    236.61    186.61    191.61    189.61    189.61
   180.61    180.61    191.61    186.61    236.61    226.61    191.61    186.61
   189.61    189.61    180.61    180.61    214.61    214.61    214.61    214.61
   214.61    214.61    214.61    214.61    198.61    198.61    198.61    198.61
   198.61    224.61    198.6     224.61    214.61    214.61
C VERTICE Z-POSITION
   131.81    138.66    146.27    141.77    133.97    133.97    132.83    131.81
   138.66    146.27    141.77    133.97    133.97    132.83    128.40    130.34
   145.26    148.54    148.08    136.54    127.96    128.40    130.34    145.26
   148.54    148.08    136.54    127.96    118.61    118.61    156.00    156.00
   129.20    148.00    157.58    160.51    160.88    139.20    129.20    129.20
   148.00    157.58    160.51    160.88    139.20    129.20    147.56    149.40
   164.26    167.64    167.68    156.20    147.54    147.56    149.40    164.26
   167.64    167.68    156.20    147.54    137.86    137.86    175.68    175.68
   129.05    141.41    154.80    172.40    150.68    130.85    146.36    174.59
   179.28    179.24    176.40    150.80    143.52    143.52    154.40    154.40
   156.72    156.72    175.15    175.15    177.93    177.93    182.12    182.12
   129.05    141.41    154.80    172.40    150.68    130.85    146.36    174.59
   179.28    179.24    176.00    150.80    152.54    152.54    159.03    159.03
   152.54    152.54    175.79    175.79    148.00    148.00    139.20    139.20
   144.2     129.1     129.1     144.2     122.1     127.05    122.1     127.05
   124.12    124.12    124.12    124.12    124.12    124.12    124.12    124.12
   142.52    140.52    140.52    142.52    132.12    132.92    132.52    132.52
   111.52    111.52    140.52    142.52    142.52    140.52    132.92    132.12
   132.52    132.52    111.52    111.52    147.92    147.92    178.52    178.52
   147.92    147.92    178.52    178.52    181.52    181.52    221.52    221.52
   111.52    132.52    111.52    132.52    157.92    157.92
C CYLINDRICAL DATA
   3
   2    2    1
   60   61
   62   63
   64
   -31.9954 135.89    147.4713  .0       .9805    .1968    55.9916
    31.9954 135.89    147.4713  .0       .9805    .1968    55.9916
    0.      133.6172  139.3729  0.       -.9837   -.1796   42.9375
C PILOT EYE POSITION
   -1.5     142.33    171.2
C CANOPY EDGES FITTED TO CYLINDRICAL SIDES
   20.783       17.875      130.91      161.175
    .9592         .0          .2828       4.98        .9995
    11.25        0.         126.175     180.135
    0.          -.1796       .9837       0.          0.
C CANOPY DISPLACEMENT OF CYLINDRICAL SIDES FROM FLAT WINDOW
   4.
C TOP WINDOW
   1.5
```

```
SMYTH,STMFZ,T1000.
ACCOUNT,HE***.
BEGIN,ATTACH,PLOTLIB.
REQUEST,TAPE13,*PF.
FTN(SL,R).
MAP,ON.
LGO.
BEGIN,PLOT,CALCOMP,TAPE13.
EXIT.
BEGIN,PLOT,CALCOMP,TAPE13.
EXIT.
      PROGRAM DRWE(INPUT,OUTPUT,TAPE4,TAPE13,TAPE2=INPUT,TAPE3=OUTPUT)
C MAINLINE, RAY TRACING FOR CANOPY OPTICAL EVALUATION
C 3 DIMENSIONAL FLAT/CYLINDRICAL CANOPY WITH OBSTRUCTIONS
      COMMON/LB/STRG(4)
      DATA STRG/"OPTICAL","DISTORTION"," ",">"/
      CALL READV
      CALL NORML
      CALL DRV
      STOP
      END
      SUBROUTINE READV
C READ IN SURFACE VERTICES
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(10
     0,8)
      COMMON/VERT/XV(200),YV(200),ZV(200),NVR(100,8)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     00),CE(10),RC(10)
      COMMON/PILOT/XO,YO,ZO
      READ(2,1000)
 1000 FORMAT()
      READ(2,1000)
      READ(2,1001)NT,NB,NC,NP,NA,ND
 1001 FORMAT(6(2X,I3))
      READ(2,1000)
      READ(2,1002)(NV(I),I=1,ND)
 1002 FORMAT(10(2X,I3))
      READ(2,1000)
      DO 10 J=1,8
      READ(2,1002)(NVR(I,J),I=1,ND)
   10 CONTINUE
      READ(2,1000)
      READ(2,1003)(XV(I),I=1,NT)
 1003 FORMAT(8(2X,F7.4))
      READ(2,1000)
      READ(2,1003)(YV(I),I=1,NT)
      READ(2,1000)
      READ(2,1003)(ZV(I),I=1,NT)
      READ(2,1000)
      READ(2,1002)NCY
      READ(2,1002)(NSC(I),I=1,NCY)
      DO 20 I=1,NCY
      KP=NSC(I)
   20 READ(2,1002)(NSP(I,K),K=1,KP)
      READ(2,1004)(XC(I),YC(I),ZC(I),AE(I),BE(I),CE(I),RC(I),I=1,NCY)
 1004 FORMAT(7(2X,F7.4))
      READ(2,1000)
      READ(2,1003)XO,YO,ZO
      RETURN
```

```
      END
      SUBROUTINE NORML
C ESTABLISH SURFACE NORMAL FOR EACH PLATE SURFACE
C SURFACE NORMALS DIRECTED TOWARD COCKPIT INTERIOR
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(10
     0,8)
      COMMON/VERT/XV(200),YV(200),ZV(200),NVR(100,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     00),CE(10),RC(10)
      COMMON/PILOT/XO,YO,ZO
      DO 10 I=1,ND
      NK=NV(I)
      DO 5 K=1,NK
      KV=NVR(I,K)
      PXV(I,K)=XV(KV)
      PYV(I,K)=YV(KV)
      PZV(I,K)=ZV(KV)
    5 CONTINUE
      K=2
    7 A1=PXV(I,K)-PXV(I,1)
      A2=PXV(I,K+1)-PXV(I,1)
      B1=PYV(I,K)-PYV(I,1)
      B2=PYV(I,K+1)-PYV(I,1)
      C1=PZV(I,K)-PZV(I,1)
      C2=PZV(I,K+1)-PZV(I,1)
      P1=SQRT(A1**2+B1**2+C1**2)
      P2=SQRT(A2**2+B2**2+C2**2)
      A=(A1*A2+B1*B2+C1*C2)/(P1*P2)
      IF(ABS(A).LT.1.) GO TO 9
      K=K+1
      IF(K.EQ.NK) GO TO 10
      GO TO 7
    9 AN=ACOS(A)
      R=1./(P1*P2*SIN(AN))
      AXN(I)=+(B1*C2-C1*B2)*R
      AYN(I)=-(A1*C2-C1*A2)*R
      AZN(I)=+(A1*B2-A2*B1)*R
   10 CONTINUE
      RETURN
      END
      SUBROUTINE DRV
      COMMON/LR/AW(9)
      AW(9)=1H>
      READ(2,800)
      READ(2,801)XH,XP,YP,ZP,AN,BN,CN,YA,ZA
      READ(2,801)XH1,XP1,YP1,ZP1,AN1,BN1,CN1,YA1,ZA1
      READ(2,800)
      READ(2,802)B0
      READ(2,800)
      READ(2,802)B01
      READ(2,800)
  800 FORMAT()
  801 FORMAT(2X,4(F10.4,2X)/6(2X,F10.4))
  802 FORMAT(2X,3(F10.4,2X),I2)
      B=B0
      RCC=.5*(XH**2+B**2)/B
      CALL COMPR(1,2,RCC,B,XP,YP,ZP,AN,BN,CN,YA,ZA)
      B1=B01
```

```
      RCC1=.5*(XH1**2+B1**2)/B1
      CALL COMPR(3,3,RCC1,B1,XP1,YP1,ZP1,AN1,BN1,CN1,YA1,ZA1)
      ENCODE(75,995,AW)B,RCC,B1,RCC1
  995 FORMAT(2X,"SIDE WINDOW",2(2X,F10.4),2X,"TOP WINDOW",2(2X,
     QF10.4))
      CALL COMPQ
      RETURN
      END
      SUBROUTINE COMPR(IJ1,IJ2,RCC,B,XP,YP,ZP,AN,BN,CN,YA,ZA)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),
     QBE(10),CE(10),RC(10)
      DO 10 IJ=IJ1,IJ2
      RC(IJ)=RCC
      XC(IJ)=-(XP-(RCC-B)*AN)*((-1)**IJ)
      YC(IJ)=YP-(RCC-B)*BN+YA
      ZC(IJ)=ZP-(RCC-B)*CN+ZA
   10 CONTINUE
      RETURN
      END
      SUBROUTINE COMPQ
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     Q0),CE(10),RC(10)
      COMMON/LR/AW(5)
      DIMENSION AD(3)
      AD(3)=1H>
      REWIND 4
      NVLL=0
      CALL CANL(NVLL)
C TRANSMISSION
      CALL DRAW
      CALL DRW(13)
      CALL DRWP(1,NVLL)
      CALL PLTSYM(.125,AW,0.,600.,5.)
      ENCODE(15,995,AD)
  995 FORMAT(2X,"TRANSMISSION ")
      CALL PLTSYM(.125,AD,0.,600.,-5.)
      CALL PLTPGE
C OPTICAL DISTORTION
      CALL DRAW
      CALL DRW(13)
      CALL DRWP(2,NVLL)
      CALL PLTSYM(.125,AW,0.,600.,5.)
      ENCODE(15,996,AD)
  996 FORMAT(2X,"OPTICAL POWER")
      CALL PLTSYM(.125,AD,0.,600.,-5.)
      CALL PLTPGE
      RETURN
      END
      SUBROUTINE CANL(NVLL)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),
     QPZV(100,8)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      COMMON/PILOT/XP,YP,ZP
      DATA PI/3.14159/
      YSC=YP+20.
      XSC=0.
      ZSO=100.
```

```
10 YSO=YSO-5.
   IF(YSO.LT.0.)RETURN
   DO 30 IA=1,180,2
   XS=XSO
   YS=YSO
   ZS=ZSO
   AN=IA-91
   AN=AN*PI/180.
   AS=SIN(AN)
   BS=0.
   CS=COS(AN)
   NCC=NC+1
   DO 20 IS=NCC,ND
   ISK=0
   IF(IS.LT.NA)CALL INTEC(1,ISK,IS,XR,YR,ZR)
   IF(IS.GT.NA)CALL INTCY(IC,ISK,IS,XR,YR,ZR)
   IF(ISK.GT.0)GOTO 25
20 CONTINUE
   GO TO 30
25 CONTINUE
   R=SQRT((XR-XP)**2+(YR-YP)**2+(ZR-ZP)**2)
   AS=(XR-XP)/R
   BS=(YR-YP)/R
   CS=(ZR-ZP)/R
   XS=XR
   YS=YR
   ZS=ZR
   CALL CALC(R,IC,IS,NVLL)
30 CONTINUE
   GO TO 10
   END
   SUBROUTINE CALC(RO,IC,IS,NVLL)
   COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(10
  0,8)
   COMMON/PILOT/XO,YO,ZO
   COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
   COMMON/IMG/TI
   DATA PI/3.14159/
   IF(CS.GE.1.)CS=.9999
   IF(CS.LE.-1.)CS=-.9999
   IF(AS.EQ.0.)AS=.0001
   XSO=XS
   YSO=YS
   ZSO=ZS
   ASO=AS
   BSO=BS
   CSO=CS
   NVLL=NVLL+1
   IF(IS.LT.NA)CALL WKTEC(ISK,IS,XR,YR,ZR,AR,BR,CR)
   IF(IS.GT.NA)CALL WKTCY(IC,ISK,IS,XR,YR,ZR,AR,BR,CR)
   AMO=AS*AR+BS*BR+CS*CR
   IF(AMO.GT.1.)AMO=1.
   IF(AMO.LT.-1.)AMO=-1.
   XMO=ACOS(AMO)*180./PI
   WRITE(4,1000)TI,XS,YS,ZS
1000 FORMAT(4F10.4)
   WRITE(3,1000)TI,XS,YS,ZS
   NX=0
   RO=0.
```

```
      CRR=SQRT(1.-CS**2)
      AO=-BS/CRR
      BO=AS/CRR
      CO=C.
C 4-DEGREE CONE DISTORTION FIELD
      DO 40 IR=1,5
      ASG=IR
      ASG=ASG*.4*PI/180.
      RS=RO*TAN(ASG)
      A=0.
      ACO=120/IR
      AK=AO
      BK=BO
      CK=CO
      ACK=ACO-1.
      DO 40 KS=1,16
      A=A+24.
      IF(A.LT.ACK)GOTO 40
      ACK=ACK+ACO
      AX=A*PI/180.
      CA=COS(AX)
      XXF=BO*ASO-AO*BSO
      XXO=ASO*CA/XXF
      XX1=(CO*ASO-AO*CSO)/XXF
      YYO=-BSO*CA/XXF
      YY1=((CO*ASO-AO*CSO)*BSO/XXF-CSO)/ASO
      AY=XX1**2+YY1**2+1.
      BY=2.*(XXO*XX1+YYO*YY1)
      CY=XXO**2+YYO**2-1.
      DY=SQRT(BY**2-4.*AY*CY)
      C1=(-BY+DY)/(2.*AY)
      B1=XXO+XX1*C1
      A1=YYO+YY1*C1
      QC=ASO*(BK*C1-CK*B1)-BSO*(AK*C1-A1*CK)+CSO*(AK*B1-A1*BK)
      IF(QC.LT.0.)GOTO 35
      C1=(-BY-DY)/(2.*AY)
      B1=XXO+XX1*C1
      A1=YYO+YY1*C1
   35 CONTINUE
      AK=A1
      BK=B1
      CK=C1
      XS=XSO+A1*RS
      YS=YSO+B1*RS
      ZS=ZSO+C1*RS
      R=SQRT((XS-XO)**2+(YS-YO)**2+(ZS-ZO)**2)
      AS=(XS-XO)/R
      BS=(YS-YO)/R
      CS=(ZS-ZO)/R
      XS=XO
      YS=YO
      ZS=ZO
      ISK=0
      IF(IS.LT.NA)CALL INTEC(1,ISK,IS,XR1,YR1,ZR1)
      IF(IS.GT.NA)CALL INTCY(IC,ISK,IS,XR1,YR1,ZR1)
      IF(ISK.EQ.0)GOTO 40
      NX=NX+1
      IF(IS.LT.NA)CALL WKTEC(ISK,IS,XR1,YR1,ZR1,AR1,BR1,CR1)
      IF(IS.GT.NA)CALL WKTCY(IC,ISK,IS,XR1,YR1,ZR1,AR1,BR1,CR1)
```

```
      AM=AS*AR1+BS*BR1+CS*CR1
      IF(AM.GT.1.)AM=1.
      IF(AM.LT.-1.)AM=-1.
      XM=ACOS(AM)*180./PI
      RO=RO+(XMO-XM)**2
   40 CONTINUE
      XN=NX
      IF(NX.EQ.0)GOTO 41
      RO=SQRT(RO/XN)
   41 WRITE(4,1000)RO
      WRITE(3,1000)XN,RO
      RETURN
      END
      SUBROUTINE INTEC(IG,ISK,IS,XR,YR,ZR)
C DETERMINES IF RAY STRIKES CONVEX SURFACE
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(10
     00,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      CK=AXN(IS)*AS+AYN(IS)*BS+AZN(IS)*CS
      XG=IG
      CK=CK*XG
      IF(CK.GE.0.) RETURN
C RAY STRIKES SURFACE IN OUTWARD DIRECTION
      I=1
      IF(XS.EQ.PXV(IS,I).AND.YS.EQ.PYV(IS,I).AND.ZS.EQ.PZV(IS,I))I=I+1
      S=(AXN(IS)*(PXV(IS,I)-XS)+AYN(IS)*(PYV(IS,I)-YS)+AZN(IS)*(PZV(IS,I
     C)-ZS))/CK
      XR=AS*S+XS
      YR=BS*S+YS
      ZR=CS*S+ZS
      A1=PXV(IS,I)-XS
      B1=PYV(IS,I)-YS
      C1=PZV(IS,I)-ZS
      P1=XR-XS
      P2=YR-YS
      P3=ZR-ZS
      IN=NV(IS)
      DO 10 I=1,IN
      IC=I+1
      IF(I.EQ.IN) IC=1
      A2=PXV(IS,IC)-XS
      B2=PYV(IS,IC)-YS
      C2=PZV(IS,IC)-ZS
      Q=P1*(B1*C2-B2*C1)-P2*(A1*C2-C1*A2)+P3*(A1*B2-B1*A2)
      IF(Q.GT.0.)RETURN
C RAY STRIKES SURFACE ON ENCLOSED SIDE OF SURFACE EDGE
      A1=A2
      B1=B2
      C1=C2
   10 CONTINUE
C RAY STRIKES ENCLOSED SURFACE
      ISK=1
      AC=AXN(IS)
      BC=AYN(IS)
      CC=AZN(IS)
      RETURN
      END
      SUBROUTINE INTCY(I,ISK,IS,XR,YR,ZR)
```

```
C COMPUTES INTERSECTION POINT OF LINE WITH CYLINDER
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(10
     0,8)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     0),CE(10),RC(10)
      COMMON/PILOT/XP,YP,ZP
C DETERMINE CYLINDERICAL SURFACE WHICH CONVEX SURFACE IS A PART OF
      DO 2 I=1,NCY
      KP=NSC(I)
      DO 2 K=1,KP
      IF(NSP(I,K).EQ.IS)GOTO 5
    2 CONTINUE
      RETURN
    5 CONTINUE
C DETERMINE INTERSECTION POINT
      X0=XC(I)
      Y0=YC(I)
      Z0=ZC(I)
      R0=RC(I)
      A0=AE(I)
      B0=BE(I)
      C0=CE(I)
      ROS=SQRT((XS-X0)**2+(YS-Y0)**2+(ZS-Z0)**2)
      A00=(XS-X0)/ROS
      B00=(YS-Y0)/ROS
      C00=(ZS-Z0)/ROS
      A=A0*AS+B0*BS+C0*CS
      B=ROS*(A0*A00+B0*B00+C0*C00)
      A1=AS-A*A0
      A2=BS-A*B0
      A3=CS-A*C0
      B1=A00*ROS-B*A0
      B2=B00*ROS-B*B0
      B3=C00*ROS-B*C0
      A=A1**2+A2**2+A3**2
      B=A1*B1+A2*B2+A3*B3
      C=B1**2+B2**2+B3**2
      AB=-B/A
      AX=B**2-A*(C-R0**2)
      IF(AX.LT.0.)AX=0.
      BB=SQRT(AX)/A
      RS=AB-BB
      IF(RS.LT.0.)RS=AB+BB
      XR=XS+AS*RS
      YR=YS+BS*RS
      ZR=ZS+CS*RS
      R=RS*(A0*AS+B0*BS+C0*CS)+ROS*(A0*A00+B0*B00+C0*C00)
      X1=X0+A0*R
      Y1=Y0+B0*R
      Z1=Z0+C0*R
      AC=(X1-XR)/R0
      BC=(Y1-YR)/R0
      CC=(Z1-ZR)/R0
C DETERMINES WHETHER RAY STRIKES ENCLOSED SURFACE
      XSS=XP
      YSS=YP
      ZSS=ZP
      CALL TRSCY(I,XSS,YSS,ZSS)
```

```
      XRR=XR
      YRR=YR
      ZRR=ZR
      CALL TRSCY(I,XRR,YRR,ZRR)
      P1=XRR-XSS
      P2=YRR-YSS
      P3=ZRR-ZSS
      X1=PXV(IS,1)
      Y1=PYV(IS,1)
      Z1=PZV(IS,1)
      CALL TRSCY(I,X1,Y1,Z1)
      A1=X1-XSS
      B1=Y1-YSS
      C1=Z1-ZSS
      IN=NV(IS)
      DO 10 II=1,IN
      IC=II+1
      IF(II.EQ.IN)IC=1
      X2=PXV(IS,IC)
      Y2=PYV(IS,IC)
      Z2=PZV(IS,IC)
      CALL TRSCY(I,X2,Y2,Z2)
      A2=X2-XSS
      B2=Y2-YSS
      C2=Z2-ZSS
      Q=P1*(B1*C2-B2*C1)-P2*(A1*C2-C1*A2)+P3*(A1*B2-B1*A2)
      IF(Q.GT.O.)RETURN
C RAY STRIKES SURFACE ON ENCLOSED SIDE OF SURFACE EDGE
      A1=A2
      B1=B2
      C1=C2
   10 CONTINUE
C RAY STRIKES ENCLOSED SURFACE
      ISK=1
      RETURN
      END
      SUBROUTINE TRSCY(I,XR,YR,ZR)
C CONVERTS COORDINATES IN CLINDRICAL COORDINATES INTO RECTANGULAR SPACE
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     00),CE(10),RC(10)
      CN=SQRT(1.-CE(I)**2)
      AN=-AE(I)*CE(I)/CN
      BN=-BE(I)*CE(I)/CN
      AP=BE(I)*CN-BN*CE(I)
      BP=-(AE(I)*CN-AN*CE(I))
      CP=AE(I)*BN-AN*BE(I)
      RO=AE(I)*(XR-XC(I))+BE(I)*(YR-YC(I))+CE(I)*(ZR-ZC(I))
      XX=XC(I)+AE(I)*RO
      YY=YC(I)+BE(I)*RO
      ZZ=ZC(I)+CE(I)*RO
      R=SQRT((XR-XX)**2+(YR-YY)**2+(ZR-ZZ)**2)
      AA=(XR-XX)/R
      BB=(YR-YY)/R
      CC=(ZR-ZZ)/R
      A=AN*AA+BN*BB+CN*CC
      IF(A.GT.1.)A=1.
      IF(A.LT.-1.)A=-1.
      ANG=ACOS(A)
      Q=AP*AA+BP*BB+CP*CC
```

```
      IF(Q.LT.0.)ANG=-ANG
      XR=ANG*RC(I)
      YR=RO
      ZR=R-RC(I)
      RETURN
      END
      SUBROUTINE WKTEC(ISK,IS,XR,YR,ZR,AR,BR,CR)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     C,8)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/IMQ/TI
      DATA TH,XN/.1,1.54/
      DATA XT/.5/
C WALK RAY THROUGH SURFACE
      TI=1.
C ENTRY SURFACE
      CA=-(AS*AC+BS*BC+CS*CC)
      IF(CA.GT.1.)CA=1.
      IF(CA.LT.-1.)CA=-1.
      SA=SQRT(1.-CA**2)
      SAP=SA/XN
      CAP=SQRT(1.-SAP**2)
      ISK=1
      A=ACOS(CA)
      AP=ACOS(CAP)
      CALL TRANS(XN,A,AP,TI)
C PASS TO OTHER SURFACE
      B=CA/XN-CAP
      AR=AC*B+AS/XN
      BR=BC*B+BS/XN
      CR=CC*B+CS/XN
      R=(AC*(XS-PXV(IS,1))+BC*(YS-PYV(IS,1))+CC*(ZS-PZV(IS,1))+TH)/CAP
      XR=XS+AR*R
      YR=YS+BR*R
      ZR=ZS+CR*R
      TI=TI*EXP(-R*XT)
C EXIT SURFACE
      CA=-(AR*AC+BR*BC+CR*CC)
      IF(CA.GT.1.)CA=1.
      IF(CA.LT.-1.)CA=-1.
      SA=SQRT(1.-CA**2)
      SAP=SA*XN
      IF(SAP.GT.1.)GOTO 10
C RAY EXITS FROM SURFACE
      CAP=SQRT(1.-SAP**2)
      A=ACOS(CA)
      AP=ACOS(CAP)
      CALL TRANS(XN,A,AP,TI)
      B=CA*XN-CAP
      AR=AC*B+XN*AR
      BR=BC*B+XN*BR
      CR=CC*B+XN*CR
      RETURN
   10 CONTINUE
C RAY CONTAINED WITHIN SURFACE
      TI=0.
      AR=XN*(AC*CA+AR)
      BR=XN*(BC*CA+BR)
```

```
      CR=XN*(CC*CA+CR)
      RETURN
      END
      SUBROUTINE WKTCY(IC,ISK,IS,XR,YR,ZR,AR,BR,CR)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(10
     C,8)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     C0),CE(10),RC(10)
      COMMON/IMQ/TI
      DATA TH,XN/.1,1.54/
      DATA XT/.5/
C WALK THROUGH CYLINDRICAL SURFACE
      TI=1.
      ISK=1
C ENTRY SURFACE
      CA=-(AS*AC+BS*BC+CS*CC)
      IF(CA.GT.1.)CA=1.
      IF(CA.LT.-1.)CA=-1.
      SA=SQRT(1.-CA**2)
      SAP=SA/XN
      CAP=SQRT(1.-SAP**2)
      A=ACOS(CA)
      AP=ACOS(CAP)
      CALL TRANS(XN,A,AP,TI)
C PASS TO OTHER SURFACE
      B=CA/XN-CAP
      AR=AC*B+AS/XN
      BR=BC*B+BS/XN
      CR=CC*B+CS/XN
      AA=AE(IC)*AR+BE(IC)*BR+CE(IC)*CR
      BB=AE(IC)*(XS-XC(IC))+BE(IC)*(YS-YC(IC))+CE(IC)*(ZS-ZC(IC))
      A1=AE(IC)*AA-AR
      A2=BE(IC)*AA-BR
      A3=CE(IC)*AA-CR
      B1=XC(IC)-XS+BB*AE(IC)
      B2=YC(IC)-YS+BB*BE(IC)
      B3=ZC(IC)-ZS+BB*CE(IC)
      A=A1**2+A2**2+A3**2
      B=A1*B1+A2*B2+A3*B3
      C=B1**2+B2**2+B3**2
      AB=(SQRT(B**2+((RC(IC)+TH)**2-C)*A))/A
      BA=-B/A
      R=BA+AB
      IF(R.LE.0.)R=BA-AB
      XR=XR+AR*R
      YR=YR+BR*R
      ZR=ZR+CR*R
      RO=R*AA+BB
      XO=XC(IC)+AE(IC)*RO
      YO=YC(IC)+BE(IC)*RO
      ZO=ZC(IC)+CE(IC)*RO
      AC=(XO-XR)/RC(IC)
      BC=(YO-YR)/RC(IC)
      CC=(ZO-ZR)/RC(IC)
      TI=TI*EXP(-XT*R)
C EXIT SURFACE
      CA=-(AR*AC+BR*BC+CR*CC)
```

```
      IF(CA.GT.1.)CA=1.
      IF(CA.LT.-1.)CA=-1.
      SA=SQRT(1.-CA**2)
      SAP=XN*SA
      IF(SAP.GT.1.)GOTO 10
C RAY EXITS FROM SURFACE
      CAP=SQRT(1.-SAP**2)
      A=ACOS(CA)
      AP=ACOS(CAP)
      CALL TRANS(XN,A,AP,TI)
      B=XN*CA-CAP
      AR=AC*B+XN*AR
      BR=BC*B+XN*BR
      CR=CC*B+XN*CR
      RETURN
   10 CONTINUE
C RAY CONTAINED WITHIN SURFACE
      TI=0.
      AR=XN*(AC*CA+AR)
      BR=XN*(BC*CA+BR)
      CR=XN*(CC*CA+CR)
      RETURN
      END
      SUBROUTINE TRANS(RN,A,AP,T)
C FRESNEL'S LAW FOR UNPOLARIZED LIGHT AT DIELECTRIC SURFACE
      F=RN**2
      F1=SQRT(F-(SIN(A))**2)
      F2=COS(A)
      RP=((F2-F1)/(F2+F1))**2
      RS=((F*F2-F1)/(F*F2+F1))**2
      R=.5*(RP+RS)
      T=T*(1.-R)*F2/COS(AP)
      RETURN
      END
      SUBROUTINE DRWP(IQ,NVLL)
      COMMON/FACT/SX,A0,B0,A1,B1
C OPTICAL DISTORTIONS, ZERO TO INFINITY
C T, TRANSMISSION, UNITY TO ZERO
      REWIND 4
      DO 10 I=1,NVLL
      READ(4,1000)FI,XR,YR,ZR
      READ(4,1000)D
 1000 FORMAT(4F10.4)
      IF(FI.LT..00001.OR.FI.GT.1.)FI=.00001
      IF(IQ.EQ.1)IC=-ALOG(FI)
      IF(IQ.EQ.2)IC=ALOG(D+1)
      IF(IC.GT.15)IC=15
      XX=(YR-5.5)*SX+100.
      YY=(ZR-111.52)*SX+100.
      CALL PLTDTS(3,IC,XX,YY,1,0)
   10 CONTINUE
      REWIND 4
      DO 20 I=1,NVLL
      READ(4,1000)FI,XR,YR,ZR
      READ(4,1000)D
      IF(FI.LT..00001.OR.FI.GT.1.)FI=.00001
      IF(IQ.EQ.1)IC=-ALOG(FI)
      IF(IQ.EQ.2)IC=ALOG(D+1)
      IF(IC.GT.15)IC=15
```

```
      XX=(YR-5.5)*SX+100.
      YY=(XR+104.)*SX+433.44
      CALL PLTDTS(3,IC,XX,YY,1,0)
   20 CONTINUE
      REWIND 4
      DO 30 I=1,NVLL
      READ(4,1000)FI,XR,YR,ZR
      READ(4,1000)D
      IF(FI.LT..00001.OR.FI.GT.1.)FI=.00001
      IF(IQ.EQ.1)IC=-ALOG(FI)
      IF(IQ.EQ.2)IC=ALOG(D+1)
      IF(IC.GT.15)IC=15
      XX=(ZR-111.52)*SX+690.42
      YY=(XR+104.)*SX+433.44
      CALL PLTDTS(3,IC,XX,YY,1,0)
   30 CONTINUE
      RETURN
      END
      SUBROUTINE DRAW
C DRAWS GRAPHIC PICTURE OF CANOPY IN THREE FOLD LAYOUT
      COMMON/DRA/MX(100),NS(100),XS(1000),YS(1000),NSY(100),NE,NX
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(10
     0,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/PILOT/XO,YO,ZO
      COMMON/FACT/SX,A0,B0,A1,B1
      NX=0
      SX=2.122
      NSS=NC+1
      A0=-5.5
      B0=100.
      A1=-111.52
      B1=100.
      XX=(YO+A0)*SX+B0
      YY=(ZO+A1)*SX+B1
      CALL BELT(1,XX,YY,1,0)
      CALL EMARK(XX,YY)
      NE=1
      DO 2 I=NSS,ND
      QS=-AXN(I)
      IF((I.LE.NC.AND.QS.LT.0.).OR.(I.GT.NC.AND.QS.GT.0.))GOTO 2
C SURFACE FACES VIEWER FROM SIDE VIEW
      XX=(PYV(I,1)+A0)*SX+B0
      YY=(PZV(I,1)+A1)*SX+B1
      NE=NE+1
      MD=1
      IF(I.LE.NC.OR.I.EQ.NA)MD=4
      CALL BELT(NE,XX,YY,MD,0)
      CALL LINS(I)
    2 CONTINUE
      A1=104.
      B1=433.44
      XX=(YO+A0)*SX+B0
      YY=(XO+A1)*SX+B1
      NE=NE+1
      CALL BELT(NE,XX,YY,1,0)
      CALL EMARK(XX,YY)
      DO 3 I=NSS,ND
      QT=+AZN(I)
```

```
      IF(((I.LE.NC.AND.QT.LT.C.).OR.(I.GT.NC.AND.QT.GT.C.))GOTO 3
C SURFACE FACES VIEWER FROM TOP VIEW
      XX=(PYV(I,1)+AO)*SX+BO
      YY=(PXV(I,1)+A1)*SX+B1
      NE=NE+1
      MD=1
      IF(I.LE.NC.OR.I.EQ.NA)MD=4
      CALL BELT(NE,XX,YY,MD,0)
      CALL LINT(I)
    3 CONTINUE
      AO=-111.52
      BO=690.42
      XX=(ZO+AO)*SX+BO
      YY=(XO+A1)*SX+B1
      NE=NE+1
      CALL BELT(NE,XX,YY,1,0)
      CALL ETIC(XX,YY)
      DO 10 I=NSS,ND
      QF=-AYN(I)
      IF(((I.LE.NC.AND.QF.LT.O.).OR.(I.GT.NC.AND.QF.GT.O.))GOTO 10
C SURFACE FACES VIEWER FROM FRONT VIEW
      XX=(PZV(I,1)+AO)*SX+BO
      YY=(PXV(I,1)+A1)*SX+B1
      NE=NE+1
      MD=1
      IF(I.LE.NC.OR.I.EQ.NA)MD=4
      CALL BELT(NE,XX,YY,MD,0)
      CALL LINF(I)
   10 CONTINUE
      NS(NE+1)=NX+1
      RETURN
      END
      SUBROUTINE BELT(IE,X,Y,MDD,NSS)
      COMMON/DRA/MD(100),NS(100),XS(1000),YS(1000),NSY(100),NE,NP
      NP=NP+1
      NS(IE)=NP
      NSY(IE)=NSS
      MD(IE)=MDD
      XS(NP)=X
      YS(NP)=Y
      RETURN
      END
      SUBROUTINE PLEM(X,Y)
      COMMON/DRA/MD(100),NS(100),XS(1000),YS(1000),NSY(100),NE,NP
      NP=NP+1
      XS(NP)=X
      YS(NP)=Y
      RETURN
      END
      SUBROUTINE EMARK(X,Y)
C MARK EYE POSITION IN CANOPY
      X=X-10.
      Y=Y-5.
      CALL PLEM(X,Y)
      X=X+10.
      Y=Y+5.
      CALL PLEM(X,Y)
      X=X-10.
      Y=Y+5.
```

```
      CALL PLEM(X,Y)
      X=X+3.
      Y=Y-1.5
      CALL PLEM(X,Y)
      Y=Y+3.
      CALL PLEM(X,Y)
      Y=Y-14.
      CALL PLEM(X,Y)
      RETURN
      END
      SUBROUTINE ETIC(X,Y)
      Y=Y-5.
      CALL PLEM(X,Y)
      Y=Y+10.
      CALL PLEM(X,Y)
      Y=Y-5.
      CALL PLEM(X,Y)
      X=X-5.
      CALL PLEM(X,Y)
      X=X+10.
      CALL PLEM(X,Y)
      RETURN
      END
      SUBROUTINE LINS(I)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/FACT/SX,A0,B0,A1,B1
      NK=NV(I)
      DO 10 K=1,NK
      K1=K+1
      IF(K.EQ.NK)K1=1
      XX=(PYV(I,K1)+A0)*SX+B0
      YY=(PZV(I,K1)+A1)*SX+B1
      CALL PLEM(XX,YY)
   10 CONTINUE
      RETURN
      END
      SUBROUTINE LINF(I)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/FACT/SX,A0,B0,A1,B1
      NK=NV(I)
      DO 10 K=1,NK
      K1=K+1
      IF(K.EQ.NK)K1=1
      XX=(PZV(I,K1)+A0)*SX+B0
      YY=(PXV(I,K1)+A1)*SX+B1
      CALL PLEM(XX,YY)
   10 CONTINUE
      RETURN
      END
      SUBROUTINE LINT(I)
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/FACT/SX,A0,B0,A1,B1
      NK=NV(I)
      DO 10 K=1,NK
      K1=K+1
      IF(K.EQ.NK)K1=1
```

```
      XX=(PYV(I,K1)+A0)*SX+B0
      YY=(PXV(I,K1)+A1)*SX+B1
      CALL PLEM(XX,YY)
   10 CONTINUE
      RETURN
      END
      SUBROUTINE DRW(IUNIT)
      COMMON/DRA/MD(100),NS(100),XS(1000),YS(1000),NSY(100),NE,NP
      COMMON/LB/STRG(4)
      COMMON/DG/XP(100),YP(100)
      DIMENSION LABEL(4)
      DATA LABEL/"SMYTH","B520","X3654","HE379"/
C PROGRAM COMPUTES LAYOUT ON 1024 UNITS FITTED TO 25 INCHES
CBY 25 INCHES DISPLAY SHEET
      CALL PLTBEG(25.,25.,1.,IUNIT,LABEL)
      CALL PLTSCA(5.,5.,200.,0.,40.96,40.96)
      CALL PLTSYM(.25,STRG,0.,201.,1.)
      DO 10 IE=1,NE
      MDD=MD(IE)
      NSS=NSY(IE)
      N1=NS(IE)
      N2=NS(IE+1)-N1
      DO 5 I=1,N2
      XP(I)=XS(N1+I-1)
      YP(I)=YS(N1+I-1)
    5 CONTINUE
      CALL PLTDTS(MDD,NSS,XP,YP,N2,0)
   10 CONTINUE
      RETURN
      END
C AAH CANOPY DATA
C NUMBER OF VERTICES, SURFACES--CONSTRAINT, FLAT, AND CYLINDRICAL
  166   16   56   58   59   64
C NO. VERTICES PER SURFACE
    4    4    4    4    4    4    4    4    4    4
    4    5    5    4    4    4    4    4    4    4
    4    4    4    4    4    7    7    7    7    4
    4    6    4    4    4    4    4    4    4    5
    4    4    5    7    7    7    7    4    4    4
    4    4    4    4    4    4    4    4    6    6
    6    6    6    4
C VERTICE ASSIGNED TO EACH SURFACE
  089  090  066  121  125  129  133  135  139  143
  145  149  153  157  137  145  001  002  003  004
  007  001  005  012  011  021  015  028  022  032
  029  033  110  035  036  111  038  039  038  109
  040  041  112  053  047  060  054  061  061  089
  094  093  100  099  098  087  077  081  101  068
  071  094  100  085
  117  114  115  122  126  130  134  136  140  144
  146  150  154  158  136  148  002  003  004  005
  014  007  004  014  012  020  016  027  023  031
  030  034  109  036  037  112  039  038  111  111
  041  110  110  052  048  059  055  064  062  090
  089  094  095  100  099  098  076  082  102  069
  072  093  099  086
  114  115  119  123  127  131  130  137  141  145
  147  151  166  159  162  163  009  010  011  012
  012  005  003  008  009  019  017  026  024  030
```

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031   109   035   043   044   044   046   034   109   037
045   112   042   051   049   058   056   063   063   066
065   070   071   076   075   074   079   083   103   070
073   092   098   087
090   066   065   124   128   132   129   138   142   139
148   152   155   160   161   164   008   009   010   011
005   002   002   009   010   018   018   025   025   029
032   110   042   042   043   037   045   033   034   036
046   045   043   050   050   057   057   062   064   065
070   069   076   075   074   088   080   084   104   065
074   091   097   088
0     0     0     0     0     0     0     0     0     0
0     165   156   0     0     0     0     0     0     0
0     0     0     0     0     017   019   024   026   0
0     041   0     0     0     0     0     0     0     035
0     0     044   049   051   056   058   0     0     0
0     0     0     0     0     0     0     0     105   066
075   090   096   0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     016   020   023   027   0
0     40    0     0     0     0     0     0     0     0
0     0     0     048   052   055   059   0     0     0
0     0     0     0     0     0     0     0     106   067
076   089   095   0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     015   021   022   028   0
0     0     0     0     0     0     0     0     0     0
0     0     0     047   053   054   060   0     0     0
0     0     0     0     0     0     0     0     107   0
0     0     0     0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     108   0
0     0     0     0
C VERTICE X-POSITION
     2.00        2.00        2.00        2.00        2.00        2.00        2.00       -2.00
    -2.00       -2.00       -2.00       -2.00       -2.00       -2.00       19.06       18.70
    14.25       12.90       11.20       14.76       17.42      -18.00      -17.60      -13.84
   -13.30      -13.24      -15.96      -17.96        8.50      -11.50      -12.04        9.08
    19.63       19.63       11.46       11.46       11.46       19.63       19.63      -19.63
   -19.63      -11.46      -11.46      -11.46      -19.63      -19.63       19.16       18.64
    14.22       13.10       11.24       14.78       17.50      -17.90      -17.60      -14.00
   -13.30      -13.28      -15.96      -17.96        8.56      -11.48      -12.14        9.16
    23.08       20.92       18.08       13.72       22.72       23.26       23.20       13.60
    13.00       15.16       16.36       22.84       16.72      -16.72      -14.28       14.28
    13.60      -13.60       -9.20        9.20       10.56      -10.56      -11.56       11.56
   -23.08      -20.92      -18.08      -13.72      -22.72      -23.26      -23.20      -13.60
   -13.00      -15.16      -16.36      -22.84       19.63       13.26       11.46      -11.46
   -13.26      -19.63      -12.00       12.00       13.26      -11.46       13.26      -11.46
   -23.75       -4.          4.         23.75       -4.        -23.75        4.         23.75
    24.         36.         36.         24.        -36.        -24.        -24.        -36.
    26.        104.        104.         26.         26.        104.         67.6        61.
    61.         67.6      -104.        -26.        -26.       -104.       -104.        -26.
   -61.        -67.6       -67.6       -61.        -46.        -24.        -22.        -56.
```

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   24.        46.        56.        22.       -10.        10.        10.       -10.
   61.        61.       -61.       -61.       -56.        56.
C VERTICE Y-POSITION
   57.50      57.50      68.37      71.57      58.98      58.98      60.30      57.50
   57.50      68.37      71.57      56.98      56.98      60.30      84.66      82.92
   83.46      86.98      98.18      98.66      96.24      84.66      82.92      83.46
   86.98      98.18      98.66      96.24      87.48      87.48      97.56      97.56
   98.45     103.49     100.92     110.92     115.61     121.40     121.50      98.45
  103.49     100.92     110.92     115.61     121.40     121.50     144.26     142.52
  142.54     146.00     157.52     158.40     156.32     144.26     142.52     142.54
  146.00     157.52     158.40     156.32     148.00     148.00     156.66     156.66
   59.20      59.20      70.14     108.42     110.90      69.78     116.49     113.25
  139.69     156.97     156.97     140.09      58.30      58.80      67.18      67.18
   69.57      69.57     108.01     108.01     112.13     112.13     145.44     145.44
   59.20      59.20      70.14     108.42     110.90      69.78     116.49     113.25
  139.69     156.97     156.97     140.09     115.52     115.52     114.82     114.82
  115.52     115.52     113.01     113.01     103.49     103.49     121.40     121.40
   57.5        5.5        5.5       57.5        5.5       57.5        5.5       57.5
   59.2       65.2      132.61     158.6       65.2       59.2      158.6      132.61
  186.61     191.61     226.61     236.61     186.61     191.61     189.61     189.61
  180.61     180.61     191.61     186.61     236.61     226.61     191.61     186.61
  189.61     189.61     180.61     180.61     214.61     214.61     214.61     214.61
  214.61     214.61     214.61     214.61     198.61     198.61     198.61     198.61
  198.61     224.61     198.6      224.61     214.61     214.61
C VERTICE Z-POSITION
  131.81     138.66     146.27     141.77     133.97     133.97     132.83     131.81
  138.66     146.27     141.77     133.97     133.97     132.83     128.40     130.34
  145.26     148.54     148.08     136.54     127.96     128.40     130.34     145.26
  148.54     148.08     136.54     127.96     118.61     118.61     156.00     156.00
  129.20     148.00     157.58     160.51     160.88     139.20     129.20     129.20
  148.00     157.58     160.51     160.88     139.20     129.20     147.56     149.40
  164.26     167.64     167.68     156.20     147.54     147.56     149.40     164.26
  167.64     167.68     156.20     147.54     137.86     137.86     175.68     175.68
  129.05     141.41     154.80     172.40     150.66     130.65     146.36     174.59
  179.28     179.24     176.40     150.80     143.52     143.52     154.40     154.40
  156.72     156.72     175.15     175.15     177.93     177.93     182.12     182.12
  129.05     141.41     154.80     172.40     150.68     130.65     146.36     174.59
  179.28     179.24     176.00     150.80     152.54     152.54     159.03     159.03
  152.54     152.54     175.79     175.79     148.00     148.00     139.20     139.20
  144.2      129.1      129.1      144.2      122.1      127.05     122.1      127.05
  124.12     124.12     124.12     124.12     124.12     124.12     124.12     124.12
  142.52     140.52     140.52     142.52     132.12     132.92     132.52     132.52
  111.52     111.52     140.52     142.52     142.52     140.52     132.92     132.12
  132.52     132.52     111.52     111.52     147.92     147.92     178.52     178.52
  147.92     147.92     178.52     178.52     161.52     161.52     221.52     221.52
  111.52     132.52     111.52     132.52     157.92     157.92
C CYLINDRICAL DATA
    3
    2    2    1
   60   61
   62   63
   64
  -31.9954 135.89    147.4713 .0       .9805      .1966      55.9916
   31.9954 135.89    147.4713 .0       .9805      .1966      55.9916
    0.     133.6172 139.3729 .0      -.9837     -.1796      42.9375
C PILOT EYE POSITION
   -1.5     142.33    171.2
C CANOPY EDGES FITTED TO CYLINDRICAL SIDES
   20.783        17.875      130.91       161.175
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 .9592          .0             .2828        4.98          .9995
  11.25      0.             126.175      180.135
   0.           -.1796        .9837        0.            0.
C CANOPY DISPLACEMENT OF CYLINDRICAL SIDES FROM FLAT WINDOW
   4.
C TOP WINDOW
   1.5
```